The Effects of Attention Deficit Hyperactivity Disorder (ADHD) and Stimulant Medication on Clinical Measures of Concussion

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A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Arts in the Department of Exercise and Sports Sciences (Athletic Training).

Chapel Hill
2011

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ABSTRACT

ASHLEY CAMERON LITTLETON: The Effects of Attention Deficit Hyperactivity
Disorder (ADHD) and Stimulant Medication on Clinical Measures of Concussion
(Under the direction of Kevin M. Guskiewicz)

The purpose of this study was to examine the effects of attention deficit hyperactivity

disorder (ADHD) and stimulant medications on concussion measures in physically active

individuals, and examine differences in practice effects between an un-medicated ADHD

group and matched controls. All participants were administered CNS Vital Signs (CNSVS),

the Balance Error Scoring System (BESS), and the Standardized Assessment of Concussion

(SAC) on three separate testing sessions (the ADHD group completed session one and two

on medication and session three off medication), each 7-9 days apart. The ADHD group had

diminished scores on measures of overall neurocognitive, psychomotor speed and processing

speed; these scores improved with medication ($p<0.05$).Our study suggests that it is

especially important to obtain a baseline measure in individuals with ADHD, because it is

difficult to compare scores to normative data and individuals with ADHD should also be

tested on their medication if possible.

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CHAPTER I

INTRODUCTION

Concussion is a common neurological injury in sports, with an estimated 1.6 to 3.8 million cases occurring each year (Langlois, Rutland-Brown et al. 2006). This may even be an underestimate as many concussions go unreported (McCrea, Hammeke et al. 2004). Concussion is a complex pathophysiological process within the brain resulting from traumatic biomechanical forces, such as a direct blow to the head, neck, face or elsewhere on the body, in which the forces are transmitted to the head (McCrory, Meeuwisse et al. 2009). The evaluation of concussion involves a multi-faceted approach including: a thorough clinical evaluation, assessment of the patient's signs and symptoms, measures of postural-stability, and cognitive or neuropsychological testing (Guskiewicz, Bruce et al. 2004; McCrory, Meeuwisse et al. 2009). Current standards recommend testing athletes on these measures prior to athletic participation, in order to serve as a baseline for comparison, in the event that the athlete sustains a concussion (Guskiewicz, Bruce et al. 2004; McCrory, Meeuwisse et al. 2009). One reason behind the use of baseline testing is to provide a unique measure of an individual's performance in the absence of injury to control for "extraneous variables," such as attentional or other disorders that may influence the testing measures (Guskiewicz, Bruce et al. 2004). An example of an attention disorder is attention deficit hyperactivity disorder (ADHD), which is a behavioral syndrome primarily characterized by hyperactivity, impulsivity and inattention (National Institute for Health and Clinical

Excellence Guidelines, 2006). Attention Deficit Hyperactivity Disorder is commonly

diagnosed in children, but it often persists into adulthood (Wolf 2001). In fact, it is

becoming more and more common for individuals with ADHD and other related disorders to

attend college, with an estimated 176,000 to 528,000 currently enrolled in universities (Wolf

2001; Shifrin, Proctor et al. 2009).

Some studies report a higher rate of injuries in individuals with ADHD, speculating

that individuals with ADHD are more likely to be inattentive and impulsive and less likely to

foresee possibly negative consequences of their behaviors (Merrill, Lyon et al. 2009). A

study by Merrill et al. showed that individuals with ADHD are more susceptible to head

injuries. Since this population may be more likely to sustain a head injury, it is essential that

individuals with ADHD are properly evaluated and treated. One way to ensure this is to

make sure athletes with ADHD are administered the recommended baseline testing on

various clinical measures of concussion. If an individual sustains a concussion, but does not

have any baseline scores to use as a comparison, then normative data must be used to assess

recovery. This may be common in high schools and other settings where there is not enough

time or resources to administer baseline testing to all athletes. Relying on normative data for

athletes with ADHD could pose a problem, because ADHD may negatively affect some of

the tasks that are often components of concussion assessment tools. For example, some

studies show that ADHD and related disorders may adversely affect working memory

(Gropper and Tannock 2009; Valera, Brown et al. 2009). However, very few studies have

examined the effect of ADHD on commonly used clinical measures of concussion. Attention

Deficit Hyperactivity Disorder and related disorders have been suggested to adversely affect

many of the neuropsychological scores commonly measured during evaluation of

concussion, including scores on verbal memory, visual memory, and working memory (Collins, Grindel et al. 1999; Solomon and Haase 2008).

Several stimulant medications are approved by the Food and Drug Administration for the treatment of ADHD in adults (Harpin 2008). Furthermore, stimulant medications have been shown to be an effective treatment for ADHD and are commonly prescribed for that purpose. However, the use of stimulant medication on scores of clinical concussion measures is poorly understood (Harpin 2008). It is possible that while on stimulant medications individuals with ADHD perform better than when off medication on clinical measures of concussion, but no previous studies have assessed this relationship. It has also been suggested that two baseline assessments might be necessary in individuals with ADHD, one while taking medication, and one without taking medication. Several studies have shown that stimulant medications can have a positive effect on cognition in adults with ADHD. However, some studies show conflicting results. Advokat et al found that stimulant medications may actually impair performance of tasks dealing with adaption, flexibility and planning in adults with ADHD (Advokat, Lane et al.). While it is well established that stimulant medications may have a positive effect on various components of cognition, the degree of the effect and specific tasks affected is still unclear.

Clinical outcome measures provide clinicians with valuable information to utilize during evaluation and management of concussion and offer quantitative values for use in making return to play decisions. Individuals with ADHD are prone to head injuries; however, the effect of ADHD on scores of commonly used concussion assessment tools is unclear. In addition, the effects of the use of stimulant medication on these measures are also unknown. Therefore, the purpose of this study was to examine the effects of ADHD and

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stimulant medications on commonly used clinical concussion measures, including the CNS Vital Signs (CNSVS), the Balance Error Scoring System (BESS), and the Standardized Assessment of Concussion (SAC) in physically active individuals. A secondary purpose was to examine differences in practice effects between individuals with ADHD compared to matched controls on commonly used clinical concussion measures, including the CNSVS, the BESS and the SAC.

Variables

Independent variables

1. Group
   a. Individuals diagnosed with ADHD
   b. Matched controls
2. Time
   a. Testing Session One
      i. ADHD Group off medication
      ii. Matched controls
   b. Testing Session Two
      i. ADHD Group off medication
      ii. Matched controls
   c. Testing Session Three
      i. ADHD Group on medication
      ii. Matched controls

Dependent variables

1. Scores on clinical measures of concussion

   a. CNSVS

      i. Neurocognitive Index (NCI)

      ii. Composite Memory Standard Score

      iii. Verbal Memory Standard Score

      iv. Visual Memory Standard Score

      v. Processing Speed Standard Score

      vi. Executive Function Standard Score

      vii. Psychomotor Speed Standard Score

      viii. Reaction Time Standard Score

      ix. Complex Attention Standard Score

      x. Cognitive Flexibility Standard Score

   b. BESS

      i. Total Error Score

   c. SAC

      i. SAC Total Score

Research Questions

1. Within individuals diagnosed with ADHD, is there a significant difference on clinical measures of concussion while on medication compared to off medication?

   a. Is there a significant difference in neuropsychological performance, as measured by CNS Vital Signs (CNSVS), in individuals with ADHD when on stimulant medication compared to off stimulant medication?

b. Is there a significant difference in balance performance, as measured by the Balance Error Scoring System (BESS), in individuals with ADHD when on stimulant medication compared to off stimulant medication?

c. Is there a significant difference in mental status, as measured by the Standardized Assessment of Concussion (SAC), in individuals with ADHD when on stimulant medication compared to off stimulant medication?

2. Is there a significant difference in scores on clinical measures of concussion between individuals with ADHD while on medication and a matched control group?

a. Is there a significant difference in neuropsychological performance, as measured by CNS Vital Signs (CNSVS), between individuals with ADHD while on stimulant medication and a matched control group?

b. Is there a significant difference in balance performance, as measured by the Balance Error Scoring System (BESS), between individuals with ADHD while on stimulant medication and a matched control group?

c. Is there a significant difference in mental status, as measured by the Standardized Assessment of Concussion (SAC), between individuals with ADHD while on stimulant medication and a matched control group?

3. Is there a significant difference in scores on clinical measures of concussion between individuals with ADHD while off medication and matched controls?

a. Is there a significant difference in neuropsychological performance, as measured by CNS Vital Signs (CNSVS), between individuals with ADHD while off stimulant medication and matched controls?

b. Is there a significant difference in balance performance, as measured by the Balance Error Scoring System (BESS), between individuals with ADHD while off stimulant medication and matched controls?

c. Is there a significant difference in mental status, as measured by the Standardized Assessment of Concussion (SAC), between individuals with ADHD while off stimulant medication and matched controls?

4. Is there a significant difference in practice effect between individuals with ADHD off their medication compared to matched controls on clinical concussion measures?

a. Is there a significant difference in practice effect on a neuropsychological testing battery, as measured by CNSVS, between individuals with ADHD off their medication compared to matched controls?

b. Is there a significant difference in practice effect on a balance task, as measured by the BESS, between individuals with ADHD off their medication compared to matched controls?

c. Is there a significant difference in practice effect on a mental status test, as measured by the SAC, between individuals with ADHD off their medication compared to matched controls on clinical concussion measures?

Research Hypotheses

1. Individuals will demonstrate improved performance on clinical measures of concussion when they are on their stimulant medication compared to while off their stimulant medication.

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a. Individuals with ADHD will demonstrate improved performance on the CNSVS when they are on their stimulant medication compared to while off their stimulant medication.

b. Individuals with ADHD will demonstrate improved performance on the BESS when they are on their stimulant medication compared to while off their stimulant medication.

c. Individuals with ADHD will demonstrate improved performance on the SAC when they are on their stimulant medication compared to while off their stimulant medication.

2. Individuals with ADHD will have diminished performance on clinical measures of concussion when on their stimulant medication compared to matched controls.

a. Individuals with ADHD will have diminished performance on the CNSVS when on their stimulant medication compared to matched controls.

b. Individuals with ADHD will have diminished performance on the BESS when on their stimulant medication compared to matched controls.

c. Individuals with ADHD will have diminished performance on the SAC when on their stimulant medication compared to matched controls.

3. Individuals with ADHD will have diminished performance on clinical measures of concussion when off their stimulant medication compared to matched controls.

a. Individuals with ADHD will have diminished performance on the CNSVS when off their stimulant medication compared to matched controls.

b. Individuals with ADHD will have diminished performance on the BESS when off their stimulant medication compared to matched controls.

c. Individuals with ADHD will have diminished performance on the SAC when off their stimulant medication compared to matched controls.

4. Individuals with ADHD will have a significantly smaller practice effect on clinical measures of concussion while off their medication compared to matched controls.

    a. Individuals with ADHD, off their medication, will have a significantly smaller practice effect on the CNSVS compared to matched controls.

    b. Individuals with ADHD, off their medication, will have a significantly smaller practice effect on the BESS compared to matched controls.

    c. Individuals with ADHD, off their medication, will have a significantly smaller practice effect on the SAC compared to matched controls.

Statistical Hypotheses

Null Hypotheses

1. There will be no significant difference in scores on clinical measures of concussion in individuals with ADHD while off medication compared to while on medication.

    a. There will be no significant difference in scores on the CNSVS in individuals with ADHD while off medication compared to while on medication.

    b. There will be no significant difference in scores on the BESS in individuals with ADHD while off medication compared to while on medication.

    c. There will be no significant difference in scores on the SAC in individuals with ADHD while off medication compared to while on medication.

2. There will be no significant difference between scores on clinical measures of concussion in individuals with ADHD, while on stimulant medication compared to matched controls.

a. There will be no significant difference between scores on the CNSVS in individuals with ADHD while on stimulant medication compared to matched controls.

b. There will be no significant difference between scores on the BESS in individuals with ADHD while on stimulant medication compared to matched controls.

c. There will be no significant difference between scores on the SAC in individuals with ADHD while on stimulant medication compared to matched controls.

3. There will be no significant difference in scores on clinical measures of concussion in individuals with ADHD while off medication compared to matched controls.

a. There will be no significant difference in scores on the CNSVS in individuals with ADHD, when off medication compared to matched controls.

b. There will be no significant difference in scores on the BESS in individuals with ADHD while off medication compared to matched controls.

c. There will be no significant difference in scores on the SAC in individuals with ADHD while off medication compared to matched controls.

4. There will be no significant difference in the practice effect on clinical measures of concussion in individuals with ADHD while off their medication compared to matched controls.

a. There will be no significant difference in the practice effect on the CNSVS in individuals with ADHD while off their medication compared to matched controls.

b. There will be no significant difference in the practice effect on the BESS in individuals with ADHD while off their medication compared to matched controls.

c. There will be no significant difference in the practice effect on the SAC in individuals with ADHD while off their medication compared to matched controls.

Alternate Hypotheses

1. There will be a significant difference in scores on clinical measures of concussion in individuals with ADHD while off medication compared to while on medication.

   a. There will be a significant difference in scores on the CNSVS in individuals with ADHD while off medication compared to while on medication.

   b. There will be a significant difference in scores on the BESS in individuals with ADHD while off medication compared to while on medication.

   c. There will be a significant difference in scores on the SAC in individuals with ADHD while off medication compared to while on medication.

2. There will be a significant difference between scores on clinical measures of concussion in individuals with ADHD, while on stimulant medication compared to matched controls.

   a. There will be a significant difference between scores on the CNSVS in individuals with ADHD while on stimulant medication compared to matched controls.

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b. There will be a significant difference between scores on the BESS in individuals with ADHD while on stimulant medication compared to matched controls.

c. There will be a significant difference between scores on the SAC in individuals with ADHD while on stimulant medication compared to matched controls.

3. There will be a significant difference in scores on clinical measures of concussion in individuals with ADHD, when off medication compared to matched controls.

a. There will be a significant difference in scores on the CNSVS in individuals with ADHD while off medication compared to matched controls.

b. There will be a significant difference in scores on the BESS in individuals with ADHD while off medication compared to matched controls.

c. There will be a significant difference in scores on the SAC in individuals with ADHD while off medication compared to matched controls.

4. There will be a significant difference in the practice effect on clinical measures of concussion in individuals with ADHD while off their medication compared to matched controls.

a. There will be a significant difference in the practice effect on the CNSVS in individuals with ADHD while off their medication compared to matched controls.

b. There will be a significant difference in the practice effect on the BESS in individuals with ADHD while off their medication compared to matched controls.

      c.   There will be a significant difference in the practice effect on the SAC in individuals with ADHD while off their medication compared to matched controls.

Assumptions

1. All participants put forth their full effort on all of the clinical concussion measures on all trials.

2. All participants were truthful and honest in reporting information, such as history of previous concussion and use of medication.

3. Individuals with ADHD were properly evaluated and diagnosed.

4. Stimulant medications were properly prescribed by physicians.

5. Participants were taking their stimulant medications as reported during the medicated condition and properly refraining from taking their stimulant medications as reported during the un-medicated conditions.

Delimitations

1. Individuals with a history of three of more concussions, lower extremity injury within the past 6 months or one or more concussion(s) within the past 6 months were excluded from this study.

2. Only BESS, CNSVS and SAC were used to assess individuals.

3. Individuals diagnosed with ADHD were only included if they were currently taking a stimulant medication.

4. Only students at the University of North Carolina at Chapel Hill were used for the study.

5. Only individuals between the ages of 18 and 25 were included in the study.

Limitations

1. Information such as history of concussion and medication use was self-reported.

2. This study only used individuals that were currently taking stimulant medications to treat ADHD; results may vary between those on stimulant drugs and those on non-stimulant drugs.

3. This study only used participants diagnosed with ADHD. The results may vary between those with ADHD and other diagnosed attention deficits.

Definition of Terms

1. ADHD- a behavioral syndrome primarily characterized by hyperactivity, impulsivity and inattention, as diagnosed by a physician at least 3 years ago.

2. Stimulant medication- a drug that increases the activity of the nervous system that has been prescribed by a physician for the treatment of ADHD; these can include immediate release methylphenidates (such as Ritalin), sustained release methylphenidate (such as Concerta XL), dexamfetamine (such as Dexedrine) and atomoxetine (such as Strattera)

3. Physically active- has consistently participated in at least 30 minutes of cardiovascular and/or resistive training at least four times per week for the past five months

4. CNS Vital Signs (CNSVS) (Appendix 1) - a series of computerized neuropsychological tests that can detect changes in neuropsychological performance over time, allowing for contributions to the assessment of concussion. The CNSVS battery assesses the following neurocognitive domains:

a. Neurocognitive Index (NCI)- average of the domain scores which provide an assessment of overall neurocognitive status

   i. The Neurocognitive Index is calculated by taking the average of all of the domain scores.

b. Composite Memory Domain Score- sum of scores from verbal and visual memory tests, which provide information about the ability to recognize and remember words and geometric figures.

   i. This score is calculated using the following equation: Verbal Memory (VBM) Correct Hits Immediate + VBM Correct Passes Immediate + VBM Correct Hits Delay + VBM Correct Passes Delay + Visual Memory (VIM) Correct Hits immediate + VIM Correct Passes Immediate + VIM Correct Hits Delay + VIM Correct Passes Delay

c. Verbal Memory Domain Score- comprised of results from verbal memory test, which measures the ability to recognize and remember words.

   i. This score is calculated using the following equation: VBM Correct Hits Immediate + VBM Correct Passes Immediate + VBM Correct Hits Delay + VBM Correct Passes Delay

d. Visual Memory Domain Score- comprised of results from visual memory test, which measures the ability to recognize and remember geometric figures.

       i. This score is calculated using the following equation: VIM Correct

          Hits immediate + VIM Correct Passes Immediate + VIM Correct

          Hits Delay + VIM Correct Passes Delay

e. Processing Speed Domain Score- results of symbol digit coding test,

  which measures the ability to automatically perform relatively simple

  cognitive tasks.

       i. This score is calculated using the following equation: Symbol

          Digit Coding (SDC) Correct Responses-SDC Errors

f. Executive Function Domain Score- results of shifting attention test, which

  measures the ability to manage multiple tasks simultaneously.

       i. This score is calculated using the following equation: Shifting

          Attention Test (SAT) Correct Responses-SAT Errors

g. Psychomotor Speed Domain Score- comprised of results from finger

  tapping test and correct responses from symbol digit coding test; score

  indicates ability to recognize and process information.

       i. This score is calculated using the following equation: Finger

          Tapping Test (FTT) Right Taps Average + FTT Left Taps Average

          + SDC Correct Responses

h. Reaction Time Domain Score- comprised of results from stroop test,

  which measures the ability to react to a simple, but increasingly difficult

  set of directions.

        i. This score is calculated using the following equation: [Stroop Test (ST) Complex Reaction Time Correct + Stroop Reaction Time Correct] /2

   i. Complex Attention Domain Score- comprised of errors on stroop test, shifting attention test and continue performance test, which is indicative of the ability to maintain focus and quickly but accurately perform tasks.

        i. This score is calculated using the following equation: Stroop Commission Errors + SAT Errors + CPT Commission Errors + CPT Omission Errors

   j. Cognitive Flexibility Domain Score- comprised of results from shifting attention test and errors on stroop test; assesses the ability to adapt and react to a continuously changing and increasingly difficult set of directions.

        i. This score is calculated using the following equation: SAT Correct Responses – SAT Errors – Stroop Commission Errors

5. Balance Error Scoring System (BESS) (Appendix 2) - an objective assessment tool developed to assess postural stability following concussion in which three different stances (double leg, single leg and tandem stance) are completed twice (once on a firm surface and once on a foam surface), for a total of six twenty second trials (Guskiewicz 2003; Hunt, Ferrara et al. 2009). Errors are totaled for each trial and include lifting hands off of iliac crests, opening eyes, stepping/tumbling/falling, moving hip into greater than thirty degrees of flexion or abduction, lifting forefoot or heel and remaining out of the test position for longer than five seconds.

a. Firm Condition Score- total number of errors during the three trials performed on the firm surface.

b. Foam Condition Score- total number of errors during the three trials performed on the foam surface.

c. BESS Total Score- total number of errors during all six trials (Firm Error Score + Foam Error Score).

6. SAC (Appendix 3) - a mental status examination designed to detect mild brain injury and concussion. The SAC takes about five minutes to administer and contains four component scores as well as a SAC total score (McCrea, Kelly et al. 1998)

   a. Orientation Score- one point is awarded for the correct response to each of the following: the day of the week, month, date, year and time of day within one hour; the maximum score is 5 points.

   b. Immediate Memory Score- a five-word list is read for immediate recall and is repeated for three trials, one point is given for each correct word remembered for a total possible 15 points.

   c. Concentration Score- the individual is asked to repeat strings of digits that increase in length from three to six numbers in reverse order and to recite the month of the year in reverse order; a total of 5 points can be earned in this section.

   d. Delayed Recall- the individual is asked to recall the original five words from the immediate memory section and is awarded one point for each correct word remembered for a total of 5 possible points.

e. SAC Total Score- the sum of the orientation, immediate memory,

   concentration and delayed recall scores; highest possible score is 30.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Concussion, a form of mild traumatic brain injury (MTBI), is a common neurological

injury that occurs in all levels of athletic participation. An estimated 1.6 to 3.8 million

people sustain a concussion each year (Echemendia and Julian 2001; Collie, Makdissi et al.

2006). The true rate of injury could be much higher because many concussions may go

unreported (McCrea, Hammeke et al. 2004). This is concerning because athletes who do not

report concussions and return to play increase their risk of a recurrent and possibly

catastrophic injury (McCrea, Hammeke et al. 2004). Also, the potential for long term effects

of repetitive MTBIs has recently been recognized (Bailes and Hudson 2001). Therefore, the

term "ding" should not be used to describe MTBIs, because it does not convey the

seriousness of the potential long-term effects of injury to the brain (Bailes and Cantu 2001;

McCrory, Meeuwisse et al. 2009).

In order to properly evaluate and manage concussion, baseline clinical measures are

taken prior to the beginning of an athletic season and repeated if an individual sustains a

concussion. Clinical measures taken following a concussion are then compared to baseline

scores to ensure a recovery of balance, neurocognition and symptoms before the individual

returns to play (Guskiewicz, Bruce et al. 2004). Ensuring that clinical measures of

concussion are valid and reliable allows for a reasonable comparison between baseline and

post-injury scores, which is needed for the proper evaluation and management of concussion. One way to increase the validity and reliability of concussion measures is to control for extraneous variables, such as ADHD. Little is known about the effect of ADHD on baseline and post-injury clinical measures, making it difficult to control for this variable during evaluation.

Colleges and universities have a growing population of individuals with ADHD,with an estimated 176,000 to 528,000 currently enrolled (Wolf 2001; Shifrin, Proctor et al. 2009). It is important to understand the influence of ADHD and use of stimulant medication on common clinical measures of concussion, in order to properly evaluate and manage concussions in this population. This is especially important since individuals with ADHD have been reported to be more prone head injuries (Merrill, Lyon et al. 2009).

Sport-Related Concussion

Definition

Concussion is a complex pathophysiological process which affects the brain and is caused by traumatic biomechanical forces, such as a direct blow to the head, neck, face or elsewhere on the body, in which the forces are transmitted to the head (McCrory, Meeuwisse et al. 2009). Concussion typically results in a temporary decrease in neurological function and the development of post-concussive symptoms that may or may not include a loss of consciousness. Acute evaluation of concussions should focus on ruling out life threatening or more severe injuries, such as a cervical spine injury or an intracranial hematoma. Once life-threatening injuries are ruled out, the evaluation should involve repeated evaluations on a multitude of measures, beginning with a sideline evaluation and continuing throughout full recovery. The majority of concussions will resolve within 7 to 10 days but can take longer

(McCrory, Meeuwisse et al. 2009). Unfortunately, there is no way to predict how long it will take an individual to recover from a concussion.

Several grading scales and return to play guidelines for guiding the management of concussion exist, but none of them are universally accepted as the "gold standard". Many of the grading scales associate the most severe injuries with a loss of consciousness (Guskiewicz, Bruce et al. 2004). However, it is widely accepted that loss of consciousness is not necessarily related to the recovery time following a concussion (Guskiewicz, Bruce et al. 2004). Therefore, current literature suggests waiting to assign a grade to a concussion until after all signs and symptoms have resolved, or simply not assigning a grade to a concussion at all (Guskiewicz, Bruce et al. 2004). Instead of focusing on grading scales, it is important for clinicians to focus on signs and symptoms, clinical evaluation and clinical measures of concussion, and to treat each case individually.

Pathophysiology

Sport related concussion is often the result of a direct blow to the head by another participant or object. Sudden acceleration or deceleration of the head can result in compressive, shear and tensile stress to cerebral tissue, leading to a diffuse injury with one of two mechanisms (linear impact or rotational/angular impact). Acceleration-deceleration injuries usually occur when an individual is moving and comes into contact with a stationary object. These injuries cause shifting of cerebral tissue within the cranium, which may cause microscopic tearing of small vessels and capillaries, resulting in localized bleeding and hematoma formation (Bailes and Cantu 2001).

Brain injuries that occur in sport can be classified as either focal or diffuse. Focal brain injuries usually result from a direct blow that causes damage to cerebral substances and

vessels, typically resulting in macroscopic lesions such as cortical or subcortical brain contusions and intracerebral hematomas (Bailes and Cantu 2001). Diffuse brain injuries vary in intensity from mild to severe, and are often caused by rotational forces from a direct or indirect blow. Diffuse injuries often result in shearing of white matter within the cortex to the midbrain and brainstem, and are not visible in diagnostic images (Bailes and Cantu 2001).

Injuries to the brain result in a neurometabolic cascade. Extracellular potassium concentrations rise because neurotransmitters, such as glutamate, open ionic channels immediately after brain injury (Bailes and Cantu 2001; Giza and Hovda 2001). The sodium-potassium pump requires more adenosine-triphosphate than usual, causing an increase in the glucose metabolism. The lack of glucose availability is most likely explanation for the brain's vulnerability to subsequent injury immediately following a previous head injury (Giza and Hovda 2001). Other physiological events associated with head injury include the generation of lactic acid, decrease in intracellular magnesium, production of free radicals, activation of inflammatory responses and alterations in neurotransmission (Giza and Hovda 2001).These physiologic changes present themselves clinically as post-concussive signs and symptoms, deficits in postural stability and neuropsychological deficits.

Signs and Symptoms

Signs and symptoms of concussion range from obvious signs, such as altered levels of consciousness, to milder self-reported symptoms, such as a headache. Concussion has been defined as an injury that involves an acceleration-deceleration mechanism in which a blow to the head results in one or more of the following: "headache, nausea, vomiting, dizziness,

balance problems, feeling 'slowed down', fatigue, trouble sleeping, drowsiness, sensitivity to light or noise, loss of consciousness, blurred vision, difficulty remembering, or difficulty concentrating" (1997). Signs and symptoms play a vital role in the evaluation of concussion and return to play decisions (McCrory, Meeuwisse et al. 2009). Therefore, one commonly used clinical measure of concussion is a Graded Symptoms Checklist (GSC). A GSC allows the athlete to denote the frequency and/or severity of symptoms, typically utilizing some type of Likert scale. The responses are then summed to obtain a total symptom score, which can be used as a measure of the severity of the concussion and help track recovery. While signs and symptoms are a vital component to the evaluation and management of concussion, other factors must also be taken into account.

Evaluation and Management

Clinicians can refer to the NATA position statement, the *Consensus Statement on Concussion in Sport: 3rd International Conference on Concussion in Sport,* and other relevant literature for guidelines in evaluating and managing concussion. Acute management of concussions should include monitoring individuals for deterioration throughout the first few hours following the injury (McCrory, Meeuwisse et al. 2009). In addition, a GSC should be administered. Once an individual is symptom free, they should be reassessed on all concussion assessment tools. This allows for comparison of post-injury scores to baseline scores, providing a more comprehensive depiction of injury status and guiding return to play decisions. Evidence suggests that the use of a single concussion assessment tool has a sensitivity of 43 to 80%, whereas the use of a combination of tests could increase the sensitivity to greater than 90% (Broglio, Ferrara et al. 2007). A general consensus is that a multi-faceted approach should be used, including a thorough clinical evaluation, along with

cognitive, postural-stability and neuropsychological testing (Guskiewicz, Bruce et al. 2004).

No one test should supersede the results of another test or evaluation.

Clinical Measures of Concussion

Mental Status

Tests of mental status evaluate the immediate neurocognitive effects of concussion, such as alterations in short-term or working memory. Several methods exist for evaluating the mental status and cognitive function of a concussed athlete. An example of a mental status test is the Standardized Assessment of Concussion (SAC). The SAC is a brief pencil and paper test that was designed for quick and easy application in the clinical or on-field setting. It takes about five minutes to administer and includes measures of orientation, immediate memory, concentration, delayed recall and a SAC total score. A neurological screening, documentation of duration of loss of consciousness (if applicable) and presence of retrograde or anterograde amnesia are also included on the SAC. There are 30 possible points for the SAC total score and lower scores indicate cognitive impairment. There are three versions of the SAC (Form A, Form B and Form C), which are utilized for retesting following concussions, in order to minimize the practice effect.

The validity and reliability of the SAC has been examined and it has been found to be both valid and reliable (Valovich, Perrin et al. 2003). However, it is possible that scores on the SAC could be affected by ADHD. Several studies have shown that ADHD negatively affects working memory, which is one of the key components measured in the SAC (Hervey, Epstein et al. 2004; Martinussen, Hayden et al. 2005; Willcutt, Pennington et al. 2005). In addition, the effect of stimulant medications on working memory in adults with ADHD is unclear.

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Postural Stability

Deficits in postural stability have been noted following concussion (Guskiewicz, Ross et al. 2001). Several methods for evaluating postural stability following concussion exist. Initially, simple examinations such as Rhomberg and stork stand were commonly used for evaluating postural stability following concussion. Currently, common methods for evaluating postural stability include the Balance Error Scoring System (BESS) and the use of force plates. The BESS involves six twenty second balance trials, including a double-leg, single-leg and tandem stance on both a firm and foam surface. Individuals are given one point for each error that they have during each trial. Errors include lifting hands off of iliac crests, opening eyes, stepping/tumbling/falling, moving hip into greater than thirty degrees of flexion or abduction, lifting forefoot or heel and remaining out of the test position for longer than five seconds. The BESS has been shown to be both valid and reliable, and has shown good concurrent validity, when compared to forceplate measures (Hunt, Ferrara et al. 2009). Some benefits of the BESS are that it is cost-effective and can be completed on the sideline following a concussion.

There is not a lot of data that exists concerning the effects of ADHD and stimulant medications used to treat ADHD on postural stability. There are a few studies that have shown that ADHD affects motor control (Leitner, Barak et al. 2007; Fliers, Vermeulen et al. 2009). In addition, another study by Shun et al showed that there was a significant difference in balance performance between an ADHD and control group. Furthermore, one study showed that that a stimulant drug used for the treatment of ADHD, helped decrease the variability in stride lengths during gait that was noticed in an ADHD group (Leitner, Barak et al. 2007). Although there is research supporting a decrease in motor control in children with

ADHD, it is still unclear whether or not adults with ADHD typically have balance or postural control deficits.

Neuropsychological

The use of neuropsychological tests, especially computerized tests, for the assessment of concussion continues to increase. Some advantages of computerized neuropsychological tests include ease of administration, shorter time period needed for testing and presence of multiple forms of tests, in order to minimize practice effects. There are several different types of computerized neuropsychological test batteries used by clinicians to assess concussions, including the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Automated Neuropsychological Assessments Matrix (ANAM), CogSport, Concussion Resolution Index and CNS Vital Signs (CNSVS). CNSVS is a newer test battery consisting of a series of computerized neuropsychological tests that can detect changes in performance over time, allowing for assistance in the evaluation of concussion. Results include scores for the following clinical domains: neurocognitive index, composite memory, verbal memory, visual memory, processing speed, executive function, psychomotor speed, reaction time, complex attention and cognitive flexibility. Performance on CNSVS has been shown to be related to the severity of brain injury and rate of recovery (Gualtieri and Johnson 2006). CSNVS has also been shown to be reliable (Gualtieri and Johnson 2006).

Many of the various neuropsychological test batteries utilize similar tasks. However, some sections of CNSVS are not included in most other neuropsychological test batteries. For example, tasks such as the Continuous Performance Test (which measures sustained attention) and the Shifting Attention Test (which measures the ability to switch from one instruction set to another quickly) are fairly unique to CNSVS. These are important

components that should be examined post-concussion, especially in individuals with ADHD. Studies have shown that executive functions, such as focus, are impaired in many individuals with ADHD. Focus is an executive function that is utilized in tasks involving sustaining focus and shifting focus to tasks (Brown 2008).

It is important that the clinical measures of concussion have been found to be valid and reliable, because there is a chance that they may need to be administered multiple times to the same athlete over a short period of time. Since a learning or practice effect may exist, individuals should not be administered follow up testing until they are symptom free and scores must return to at or above baseline before return to play is considered. Comparing post-injury scores on clinical measures of concussion to baseline scores gives clinicians a quantitative measure for making return to play decisions.

Return to Play Following Concussion

While no specific return to play guidelines for concussions have been established, a basic progression has been agreed upon. Once an individual is completely symptom free (determined using a graded symptom scale or symptoms checklist), he or she should be re-administered concussion assessment tools. Follow-up assessments should be performed both at rest and after exertional maneuvers (Guskiewicz, Bruce et al. 2004). Baseline measures for neuropsychological and postural stability tests should be conducted prior to the beginning of the athletic season, to determine "normal" scores for each individual (Guskiewicz, Bruce et al. 2004). The post-injury assessments can then be compared to the baseline assessment to determine that the individual has returned to a pre-injury status.

Once an individual is symptom free at rest and at exertion and clinical measures suggest neurocognitive and postural control recovery, he or she can be returned to limited

activity. The individual should avoid activities that place them at an increase risk of

sustaining a recurrent head injury for the first few days back to activity (Guskiewicz, Bruce

et al. 2004). The individual should also be educated on the signs and symptoms of

concussion and told to notify the sports medicine professional and discontinue activity if any

of these signs and symptoms return. If the individual is able to perform exertional activities

without any return in signs and symptoms, then he or she should be reassessed on the clinical

measures of concussion. Once these measures return to baseline and the individual is able to

perform activities symptom free, he or she can then be returned to full activity (Guskiewicz,

Bruce et al. 2004). The athlete should also be taught prevention techniques before returning

to play as individuals who sustain a head injury are more likely to sustain additional head

injuries in the future (McCrory, Meeuwisse et al. 2009).

Injury Risks

Certain individuals are thought to be at an increased risk of sustaining a head injury.

For example, individuals with ADHD have been shown to be at a greater risk of sustaining a

head injury than the general population (Merrill, Lyon et al. 2009). Individuals with ADHD

are thought to be at least 1.5 times greater than those without ADHD to injure themselves

and are at a significantly higher risk of suffering a serious injury, such as a fracture,

intracranial injury or internal injury (Merrill, Lyon et al. 2009). Furthermore, it has been

shown that individuals with ADHD are significantly more likely to be injured while riding a

bicycle, driving a car, to receive head injuries and to be hospitalized for unintentional injuries

(Merrill, Lyon et al. 2009). Individuals with ADHD are more likely to be inattentive and

impulsive and therefore less likely to foresee possibly negative consequences of their

behaviors (Merrill, Lyon et al. 2009). Sports medicine professionals should be aware of the

fact that individuals with ADHD are at a greater risk for injury and should instruct them on

proper injury prevention techniques. Furthermore, since this population is more likely to

sustain a head injury, it is essential that individuals with ADHD are properly evaluated and

treated for head injuries. Clinicians who work with patients with ADHD should be familiar

with the syndrome in order to provide the proper care.

Attentional Deficit Hyperactivity Disorder

Definition

ADHD is a behavioral syndrome primarily characterized by hyperactivity,

impulsivity and inattention (National Institute for Health and Clinical Excellence Guidelines,

2006). Individuals can possess all of the symptoms, or they can be characterized as

predominantly hyperactive/impulsive and impulsive, or predominantly inattentive (National

Institute for Health and Clinical Excellence Guidelines, 2006). Initially, ADHD was

associated with disruptive behavior during childhood that usually subsided in early

adolescence. However, recent research has caused a major shift in the view of ADHD and it

has begun to be described as a disorder of "cognitive function" (Brown 2008; Gropper and

Tannock 2009). It has been shown that many individuals with ADHD have more difficulty

with focusing their attention on necessary tasks and effectively using working memory, than

they do with behavioral problems (Brown 2008). In addition, impairments associated with

ADHD may not become apparent until late adolescence or early adulthood, when individuals

are required to manage a wide range of tasks themselves (Brown 2008). Further research is

necessary to fully understand how people with this syndrome are affected throughout life.

Etiology

The etiology and physiology of ADHD are still poorly understood. Several studies have identified possible factors associated with the development of ADHD, including genetic effects, environmental effects, and structural abnormalities of the brain (Hay, Bennett et al. 2007). Genetics may play an effect on the incidence of ADHD, because there is a higher occurrence in monozygotic twins than dizygotic twins (Reynolds, 2008). In addition, siblings of hyperactive children are twice as likely to have the disorder (Wender and Rothkegel 2000). Although there is some evidence that genetics may play a role in ADHD, strong evidence does not exist.

Similarly, there is some small evidence that several environmental factors may be linked with ADHD. Food additives, colorings, preservatives and sugar have been examined and found to be possible causes of hyperactive behavior (McCann, Barrett et al. 2007). Psychosocial factors may also play a role in ADHD, such as prolonged emotional distress, stressful psychic events and anxiety-inducing events (Brock, et al., 2009). In fact, not only do these factors seem to be related to the cause of ADHD, they all seem to be involved with the exacerbation of the disorder (Brock et al, 2009). There is little research in this area and no strong evidence to support the association of any one environmental factor with ADHD.

Finally, there is some evidence to suggest that structural abnormalities of the brain may be the cause of ADHD. Several neurotransmitters have been associated with ADHD. Furthermore, at a younger age, there has been some correlation between electroencephalogram (EEG) patterns and ADHD suggesting that there may be a relationship between the structure of the brain and ADHD. Most research in this area has examined specific characteristics of the brain and their associations with ADHD, focusing on inhibitory and executive processes mediated by neural circuits in prefrontal cortex and striatum and the

systems that innervate these circuits (Halperin and Schulz 2006). The NIH-Centers for

Disease Control stated that while research suggests a central nervous system basis for

ADHD, more research is needed in order to firmly categorize ADHD as a brain disorder

(NIH, 2000). While some progress has been made in determining the pathophysiology of

ADHD, much more research is needed. This research is vital as it guides the diagnosis and

management of ADHD and may help explain the signs and symptoms of the disorder.

Signs and Symptoms

There is some debate about the onset of signs and symptoms of ADHD. Some

believe that signs and symptoms must have an onset of seven years of age or earlier, while

others believe that signs and symptoms may not become evident until late adolescence or

even early adulthood (Brown 2008). Recently, the general consensus in diagnosis of ADHD

has been that the age of onset should not supersede significant impairment and other

diagnostic criteria (Brown 2008). In fact, a later age of onset makes sense because cognitive

functions that are affected by ADHD are the slowest to mature (Brown 2008). In addition,

individuals may not notice the signs or symptoms of ADHD until they are required to make

decisions and manage their time on their own.

Signs and symptoms of ADHD can typically be broken into three different categories:

inattention, hyperactivity and impulsivity. Individuals who are inattentive typically report

symptoms of not giving close attention to details, making careless mistakes in schoolwork or

work, trouble paying attention to necessary tasks, inability to listen when spoken to, inability

to follow instructions or failure to complete tasks, difficulty organizing activities, avoidance

of schoolwork or homework, frequent loss of important objects, being easily distracted, or

being forgetful in daily activity to a point that it is disruptive and inappropriate for their

developmental level (CDC 2000). Individuals with hyperactive tendencies present with symptoms of fidgeting with hands or feet, squirming in seat, often getting up from seat when expected to remain seated, often running or climbing when it is not appropriate, trouble playing or enjoying leisure activities quietly, inability to sit still, and excessive talking (CDC 2000). Individuals who are characterized as impulsive may blurt out answers before questions have been finished, have trouble waiting his/her turn, or interrupt or intrude on others (CDC 2000). Clinicians must recognize that ADHD presents with a variety of signs and symptoms.

Signs and symptoms of ADHD often vary depending on situations. For example, individuals with ADHD may report the ability to focus their attention on a few specific tasks that they truly enjoy, such as playing a sport (Brown, 2008). However, they are unable to focus on other necessary tasks, such as completing school work. There is actually a chemical cause behind this variability in symptoms. When individuals are confronted with tasks that they find appealing, the brain provides chemical stimulus that activates the necessary executive functions (Brown 2008).

Many of the signs and symptoms associated with ADHD are also common post-concussive symptoms. This creates difficulty in differentiating between symptoms that were present prior to injury and those induced by injury in athletes with ADHD. For example, a common symptom of concussion is difficulty concentrating, which is also a hallmark symptom of ADHD. In addition, working memory, which is a main component of several neuropsychological tests used to assess concussion, is often impaired in individuals with ADHD. Because of the overlap in signs and symptomology, clinicians may have a difficult

time distinguishing whether the individual's difficulty concentrating, trouble with working memory, or other observed deficits are a result of a concussion or due to ADHD.

Diagnosis

Currently two main diagnostic criteria for ADHD are being used. The International Classification of Mental and Behavioural Disorders 10th revision (ICD-10), a relatively narrow diagnostic category focusing on individuals with more severe impairment, is one of the tools being used. The Diagnostic and Statistical Manual of Mental Disorders 4th edition (DSM-IV) is also commonly used and utilizes a broader definition of ADHD with several subtypes. These diagnostic tools include behavior checklists. The DSM-IV utilizes an ADHD rating scale (Appendix 4) which determines a diagnosis of ADHD based on the presence of either 6 or more symptoms of inattention or 6 or more symptoms of hyperactivity-impulsivity that have been present for at least 6 months and have been disruptive and inappropriate for developmental level (Brimble 2009). In addition, some of the impairments must be present in two or more settings and there must be evidence of significant impairment in social, school or work functioning (CDC 2000). Finally, the symptoms cannot be due to another mental disorder (CDC 2000). The DSM-IV identifies three subtypes of ADHD including predominantly inattentive, predominantly hyperactive-impulsive and combined. The predominantly inattentive diagnosis is characterized by having six or more inattention symptoms, but less than six hyperactivity-impulsivity symptoms. The predominantly hyperactive-impulsivity type is characterized by six or more hyperactive-impulsivity symptoms, but less than six inattention symptoms. The combined type is characterized by six or more inattention and hyperactive-impulsivity symptoms.

While criteria exist for the diagnosis of ADHD, they should not be used as the sole tool for diagnosis. Not only should the assessment include a self-report of symptoms, but it should involve the report of symptoms observed by the individual's parent or another close relative or friend (DuPaul, et al., 2009). In addition, it should involve a direct assessment of attention and impulsivity (DuPaul, et al., 2009). Furthermore, neuropsychological tests may be used to help identify deficits in executive function. Once the proper diagnosis is made, the appropriate treatment plan should be developed.

Treatment

Several different treatment types exist for the management of ADHD. The majority of therapies can be categorized as behavioral therapy, non-stimulant medication or stimulant medication. Behavioral therapy involves the modification of daily habits in order to help control the signs and symptoms of ADHD. For example, healthcare professionals may suggest using a food and drink log to determine any possible relationships between diet and hyperactive behavior (National Institute for Health and Clinical Excellence Guidelines, 2006). If a relationship exists, then those foods and/or drinks are essentially removed from the individual's diet. Behavioral therapy also includes education programs with management strategies, such as using positive reinforcement for good behavior and negative consequences for poor behavior (National Institute for Health and Clinical Excellence Guidelines, 2006). If behavioral therapy is not successful in treating an individual's ADHD, then individuals often turn to medication to help relieve their signs and symptoms.

Medication

Stimulant medications are the most commonly prescribed medications for college aged individuals with ADHD (DuPaul, Weyandt et al. 2009). Stimulant medications have

been shown to be an effective treatment for ADHD and several stimulant medications have

been approved by the Food and Drug Administration for the treatment of ADHD in adults

(Brown 2008). The most commonly used stimulants include immediate release

methylphenidates (such as Ritalin), sustained release methylphenidate (such as Concerta

XL), dexamphetamine (such as Dexedrine) and atomoxetine (such as Strattera) (Harpin

2008). Healthcare professionals must be careful when prescribing stimulant medications for

ADHD. Often times, these medications do not follow the guidelines for patients and the

effective dosing is not consistently related to age, weight or symptom severity (Brown 2008).

Therefore, patients should be started on a minimal dose and then gradually increase until the

optimal dose is identified. Patients should be asked about how the medication works during

different times of the day and during different tasks. The timing of medication should also

be considered as different patients need their medication to be most effective at different time

periods throughout the day and sometimes varying times from day to day. Prescription of

stimulant medications should involve a comprehensive evaluation and follow up regarding

the effectiveness of medication.

Some research has been conducted examining the effects of stimulant medication on

clinical measures of ADHD, with varying results (Froehlich, McGough et al. ; Sprafkin,

Mattison et al.). However, no previous research studies have determined whether individuals

with ADHD should be administered baseline clinical measures of concussion while on or off

their medication. This could potentially make a difference on the interpretation of scores and

ultimately affect evaluation and management of concussion. Stimulant medications have

been shown to produce a significant improvement in symptom severity, which could lead to

changes in scores on clinical concussion measures. In fact, one study showed that stimulant

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medications increased performance on a neuropsychological task in individuals with ADHD (Mikami, Cox et al. 2009). Another possible interaction that stimulant medication could have on clinical measures of concussion is the overlap between common side effects of stimulant medications and signs and symptoms of concussion. Some overlapping symptoms include irritability, vomiting and headache (Cowles 2009; Mikami, Cox et al. 2009).

Effect of ADHD on Cognition

Attentional Deficit Hyperactivity Disorder has been shown to have an effect on executive functioning. Deficits in executive function can affect a wide range of cognitive functions that are critical for managing the multiple tasks of daily life (Brown 2008). Brown identifies six executive functions that are typically impaired in individuals with ADHD. One of these functions is activation, which involves organizing tasks and materials. An individual with impaired activation may report excessive procrastination (Brown 2008). Focus is also often affected and deficits may be described as being easily distracted or constantly having to re-read portions of a book for the passage to become meaningful (Brown 2008). Individuals also have difficulty with effort, which involves regulating alertness, sustaining effort and processing speed (Brown 2008). Emotional abnormalities are also described in which individuals have difficulty managing frustration, anger, disappointment and other emotions (Brown 2008). Finally, difficulty in monitoring and regulating self-action may be described and individuals may have difficulty using working memory and accessing recall (Brown 2008).

Several studies have also shown the adverse effect of ADHD on cognitive tasks that incorporate visual, verbal, and working memory (Valera, et al., 2009; Collins, et al., 1999; Solomon & Haase, 2008; Gropper & Tannock, 2009). Working memory, which allows

individuals to retain and manipulate information for several seconds, has been shown to be impaired in individuals with ADHD (Hervey, Epstein et al. 2004; Martinussen, Hayden et al. 2005; Willcutt, Pennington et al. 2005). Although executive function deficits that can be detected using neuropsychological tests are often associated with ADHD, they do not always exist. Therefore, neuropsychological tests should not be used as the sole tool for the diagnosis of ADHD.

Effect of ADHD on Balance

It is also possible that ADHD could have a negative effect on balance. Some studies have shown that ADHD is associated with motor problems (Fliers, et al., 2009). These studies have examined functions such as control during movement, gross motor movements, fine motor movements and overall coordination (Fliers, Vermeulen et al. 2009). Poor motor performance was noted in the ADHD group compared to the control group (Fliers, Vermeulen et al. 2009). In addition, it has been shown that adults with ADHD often have linguistic and spatial deficits along with executive function deficits (Wolf 2001). Therefore, it is possible that individuals with ADHD may have decreased balance. This could be important to note when using balance as measure of concussion assessment.

ADHD and Clinical Measures of Concussion

While the effect of ADHD on cognitive function has been shown throughout the literature, there is limited research regarding the affect of ADHD on commonly used clinical concussion measures. Normative data for clinical concussion measures exists, but the effect of ADHD on these scores is not taken into account. In the absence of a baseline evaluation, deciphering differences between pre-existing deficits and those that are a result of head injury can be very difficult. One study by Collins et al. found that learning disabilities were

related to lower baseline cognitive performances on a battery of neuropsychological concussion measures in a multi-university sample of college football players (Collins, Grindel et al. 1999). Another study by Solomon et al. collected baseline data for NFL players and found that individuals with a diagnosed learning disability, some of which had ADHD, had decreased verbal and visual memory scores (Solomon and Haase 2008). Although these studies suggest a decreased performance in individuals with ADHD, further research must be conducted. In addition, there is a lack of research examining the effect of stimulant medications on clinical measures of concussion.

Rationale for Study

There is little research examining ADHD in the collegiate population. The few studies that have been conducted examining college students with ADHD are not without their limitations. The studies have a lack of comprehensive clinical evaluations confirming the diagnosis of ADHD or have used measures that have not been deemed valid and reliable in the college aged population (DuPaul, Weyandt et al. 2009). On the other hand, there have been numerous studies examining the validity and reliability of using multiple concussion assessment tools in conjunction to assess concussion. Most of the commonly used tools have been deemed both valid and reliable.

In order to be able to diagnose, evaluate and manage concussion properly, it is important to correctly interpret scores on clinical measures of concussion. Limited research is available examining the effects of ADHD on clinical measures of concussion. Understanding the relationship between ADHD and concussion evaluation is important because clinicians are faced with the challenging task of properly testing athletes prior to and following injury. Complicating this issue is the fact that the effect of stimulant medication on scores of

concussion measures is also poorly understood. Therefore, the purpose of this study was to examine the effects of ADHD and stimulant medications used to treat ADHD on commonly used clinical measures of concussion, including CNS Vital Signs (CNSVS), the Balance Error Scoring System (BESS) and the Standardized Assessment of Concussion (SAC). A secondary purpose was to examine the test-retest reliability of commonly used clinical concussion measures, including CNSVS, the BESS and the SAC in individuals with ADHD compared to matched controls.

CHAPTER III

METHODS

Participants

Participants in the study consisted of a convenience sample of thirty-four physically active college students. Seventeen participants (nine males and eight females) were in the ADHD group (age: 21.294 ± 2.02 years, previous number of concussions: 0.65 ± 0.70) and seventeen participants (nine males and eight females) were in the matched control group (age: 21.294 ± 2.05 years, previous number of concussions: 0.65 ± 0.70). Participants in the control group were matched by gender, age and concussion history to participants in the ADHD group. Participants included in the ADHD group had to meet the following criteria: 1) declare that they have been diagnosed with ADHD, 2) complete the ADHD rating scale to confirm they meet the ADHD criteria (Appendix4), 3) provide proof of a prescription for stimulant medication. The ADHD rating scale, developed as part of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV), consists of a series of questions regarding inattentiveness and hyperactivity. This tool has been used as a diagnostic criterion for ADHD. Although, not commonly used in isolation, it identifies three separate sub-types of ADHD including inattentive, hyperactive/impulsive and a combined type. In order to participate each ADHD participant had to meet the criteria of one of the three sub-types (Appendix 4). All matched controls completed the ADHD rating scale and were not included if they met the criteria of one of the three sub-types.

All participants were physically active, defined as consistently participating in at least 30 minutes of cardiovascular and/or resistive training at least 4 times per week for the past five months. Individuals reporting a history of three or more previous concussions, known vestibular dysfunction, or any lower extremity injury or concussion in the past six months were excluded from both groups.

Procedures

Participants reported to the University of North Carolina at Chapel Hill Matthew Gfeller Sport-Related Traumatic Brain Injury Research Center for testing. All participants were administered the CNSVS, BESS and SAC on three separate occasions, between seven and nine days apart. The means and standard deviations for time between testing session is presented in Table 3.1. The testing order was counterbalanced between all participants at the first testing session (Table 3.2). Participants then repeated the same test order at all three sessions. Prior to data collection, all participants filled out a questionnaire to ensure that all inclusion and exclusion criteria were met. All participants expressed their agreement to participate by signing and informed consent approved by the Institutional Review Board at the University of North Carolina at Chapel Hill.

The control group was administered the CNSVS, BESS and SAC on three separate occasions, without any change in conditions. For the participants in the ADHD group, the first two testing sessions were completed off medications, while the third testing session was completed on medication. For the non-medicated testing session, ADHD participants did not take their stimulant medication for at least 24 hours prior to the testing session. For the medicated testing session, participants in the ADHD group took their stimulant medication within three to four hours prior to the testing session. All three testing sessions for each

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participant occurred exactly seven days apart and were held at approximately the same time of day (within two hours of prior testing sessions). For morning testing sessions, testing was completed prior to the participant's first class. For evening testing sessions, testing was completed at least four hours after the conclusion of the participant's last class and the participant had three hours or less of classes on the testing day. Every effort was made to avoid disrupting the normal medication schedule of participants with ADHD. A questionnaire was also administered to all participants prior to each testing session, which included information regarding hours of sleep, hydration and eating habits (Appendix 5).

Measurement and Instrumentation

CNS Vital Signs (CNS Vital Signs, LLC, Chapel Hill, NC) consists of a series of computerized neurocognitive tests. One of the purposes of CNSVS is to detect changes in neurocognitive performance over time, allowing for assistance in the evaluation of concussion. Some advantages of CNSVS include millisecond timing, allowing for accurate detection of even small cognitive changes, immediate automated scoring, ease of exporting the scores and randomized presentation of data, allowing for long-term repeated administration of the test. In addition, CNSVS allows for customized testing, meaning the test administrator can choose which tests to include in each evaluation. CNSVS subtests are described in Appendix 1. A multitude of cognitive domains are included and are known to be sensitive to most causes of mild cognitive dysfunction (Gualtieri, CT & Johnson, LG, 2006). Results include scores for the following clinical domains: neurocognitive index, composite memory, verbal memory, visual memory, processing speed, executive function, psychomotor speed, reaction time, complex attention and cognitive flexibility. Each participant was instructed to answer quickly while also trying to be correct, read all instructions, and to try to

sustain their attention throughout the entire test. CNSVS has been shown to be both valid

and reliable (Gualtieri, CT & Johnson, LG, 2006). All participants were administered the test

in a quiet, controlled setting. The test was administered to one to two athletes at a time, with

at least one computer between participants. Participants were given a set of instructions prior

to test administration. Participants were told to be sure to read all instructions and to sustain

their full effort throughout the test. They were also instructed that the goal for most of the

tasks was to be respond as quickly as possible, while still being accurate. In addition, they

were told that some of the tasks have practice tests and some of the tasks are similar. Finally,

participants were instructed to notify the test administrator if they had any questions

throughout the test. These instructions were given prior to each test administration. The test

took approximately 30 minutes for each participant to complete.

The BESS is an objective assessment tool developed to assess postural stability

following concussion. It is portable, cost-effective and can be used in the absence of a more

expensive or sophisticated tool (Guskiewicz 2003; Hunt, Ferrara et al. 2009). It is also one

of the most commonly used concussion assessment tools amongst athletic trainers (Ferrara,

McCrea et al. 2001). The BESS involves three different stances (double leg, single leg and

tandem stance), which are completed twice (once on a firm surface and once on an unstable

surface), for a total of six twenty second trials (Guskiewicz 2003; Hunt, Ferrara et al. 2009).

An Airex medium-density foam pad (20" L x 16.4" W x 2 1/2" H) (Power Systems Airex

Balance Pad 81000, Knoxville, TN) was used for the unstable surface. For balance in the

double leg stance, participants were instructed to stand as tall as possible with hands on iliac

crest and eyes closed, while maintaining balance with both feet touching. For the single leg

stance, participants were instructed to stand as still as possible with hands on iliac crests and

eyes closed, while maintaining balance on their non-dominant limb with their dominant limb

in approximately twenty degrees of hip flexion and forty-five degrees of knee flexion. For

balance in the tandem stance, participants were instructed to stand heel-to-toe with their non-

dominant limb in back, hands on their iliac crests and eyes closed. Leg dominance was

defined as whichever leg the participant would use to kick a soccer ball for maximum

distance. If participants moved out of the test position at any point, they were reminded to

return to a stable testing position as soon as possible and continue with the trial. Each stance

was demonstrated prior to data collection. The test took about five minutes to administer. All

trials were videotaped and scored after testing to help ensure accuracy. Errors included

lifting hands off iliac crests, opening eyes, stepping, stumbling or falling, moving the hip into

greater than thirty degrees of flexion or abduction, forefoot or heel losing contact with the

ground or remaining out of the testing position for more than five seconds (Riemann and

Guskiewicz 2000). Errors were recorded for each 20-second trial by the primary

investigator. Errors were summed for firm stance trails, foam stance trials, and total of all six

trials. The BESS has found to be both valid and reliable (Broglio, Macciocchi et al. 2007;

Hunt, Ferrara et al. 2009).

The SAC is a paper-and-pencil test that is used to evaluate mental status. The SAC

was designed in order to provide immediate information to athletic trainers and other medical

providers regarding the management of head injuries. It was created for the purpose of rapid

sideline evaluation following a head injury sustained during a sporting event. Along with the

BESS, the SAC is also one of the most commonly used concussion assessment tools amongst

athletic trainers (Ferrara, McCrea et al. 2001). The SAC includes assessments of orientation,

immediate recall, concentration, and delayed recall. The SAC has been shown to be both

valid and reliable in college athletes (McCrea, Kelly et al. 1998; Valovich, Perrin et al. 2003; Bleiberg, Cernich et al. 2004). Participants were administered a different form of the SAC containing new words lists and digit recall content at each testing session to minimize a practice effect. The SAC was administered in a quiet, controlled environment. Each test took about five minutes to administer.

Data Reduction

For data reduction, all recorded scores on the BESS and SAC were entered manually into SPSS. Output scores from CNSVS were exported into an excel spreadsheet. A single participant in the ADHD group presented with invalid CNSVS scores during the second session, due to having a Neurocognitive Index score of less than one hundred. The participant's second session CNSVS data were excluded from all analyses thereby excluding them from all CNSVS analyses. It was quite evident that the participant did not put forth full effort on the second testing session perhaps due to being highly symptomatic, with a symptom score of 38.

Data Analysis

All data were analyzed using SPSS Version 17.0 (SPSS Inc, Chicago, Illinois). An a priori alpha level was set at 0.05. We performed separate 2 (group) x 2 (session—2 and 3) mixed model repeated measures ANOVAs to address our first three research questions. Thus, these analyses allowed us to determine the effect of medication use on outcome measures within the ADHD group (on vs. off; research question 1), and to compare the differences in outcome measures between the control group and the ADHD group under both on (research question 2) and off (research question 3) medication conditions. Tukey post hoc analyses were employed following statistically significant omnibus tests for interaction effects. In

addition, in order to examine the differences in practice effects between the control group

and the ADHD group when off their medication (research question 4), separate 2 (group) x 2

(session—1 and 2) mixed model repeated measures ANOVAs were utilized. Tukey post hoc

analyses were again employed when the omnibus test for interaction effects were significant.

A summary of data sources and analyses is presented in Table 3.3. An executive summary is

presented in Appendix 6.

Table 3.1: Time between testing sessions

Group	Time between testing session 1 and testing session 2 (days)	Time between testing session 1 and testing session 2 (days)
ADHD (n=17)	7.12 ± 0.33	7.47 ± 0.72
Control (n=17)	7.24 ± 0.56	7.24 ± 0.44
Both (n=34)	7.18 ± 0.46	7.33 ± 0.60

Table 3.2: Possible Counterbalance Order

Testing Order Option	First Test	Second Test	Third Test
1	BESS	CNSVS	SAC
2	BESS	SAC	CNSVS
3	SAC	BESS	CNSVS
4	SAC	CNSVS	BESS
5	CNSVS	BESS	SAC
6	CNSVS	SAC	BESS

Table 3.3: Data Summary Table

Research Question	Description	Data Source	Comparison	Method
1	Is there a significant difference in scores on clinical measures of concussion in individuals with ADHD while **on medication** and **off medication?**	**IV:** Session & Group **DV:** Scores on CNSVS (10), BESS (1) and SAC (1)	Clinical measure scores of session two (ADHD) vs. session three (ADHD)	Twelve 2 (group) x 2 (session) repeated measures mixed model ANOVAs, with Tukey post hoc when the omnibus test for interaction effects were significant
2	Is there a significant difference in scores on clinical measures of concussion between individuals with **ADHD while on medication** and a **matched control group?**	**IV:** Session & Group **DV:** Scores on CNSVS (10), BESS (1) and SAC (1)	Clinical measure scores of session three (ADHD) vs. session three (Control)	
3	Is there a significant difference in scores on clinical measures of concussion between individuals with **ADHD while off medication** and a **matched control group?**	**IV:** Session & Group **DV:** Scores on CNSVS (10), BESS (1) and SAC (1)	Clinical measure scores of session two (ADHD) vs. session two (Control)	
4	Is there a significant difference in practice effect between individuals with **ADHD off their medication** compared to **matched controls** on clinical concussion measures?	**IV:** Session & Group **DV:** Scores on CNSVS (10), BESS (1) and SAC (1)	Clinical measure scores of session one (ADHD and Control) vs. session two (ADHD and Control) Clinical measure scores of session two (ADHD and Control) vs. session three (ADHD and Control)	Twelve 2 (group) x 2 (session) repeated measures mixed model ANOVAs, with Tukey post hoc when the omnibus test for interaction effects were significant

CHAPTER IV

RESULTS

The primary purpose of this study was to examine the effects of stimulant medication on clinical concussion measures in physically active individuals diagnosed with ADHD. The secondary purpose was to examine the effects of ADHD in a physically active population on repeated sessions of a standard concussion assessment battery compared to a matched control group without ADHD. Our study included an ADHD group with five participants classified as hyperactive/impulsive, five participants classified as inattentive and seven participants classified as combined type by the DSM-IV ADHD Rating Scale. The ADHD and control group both had eight participants who had never sustained a concussion, seven participants who had sustained one concussion and two participants who had previously sustained two concussions. Demographic information for the participants is presented in Table 4.1. Descriptive and statistical results are presented in Table 4.2 (sessions two and three) and 4.3 (sessions one and two). A summary of results is presented in Table 4.4.

Research Question One

Research question one examined the effects of stimulant medication in the ADHD group relative to matched controls on scores of concussion assessment tools comparing session two (ADHD-off medication) to session three scores (ADHD-on medication).

CNSVS

We did not observe any significant group x session interactions or main effects for scores on **composite memory**, **verbal memory**, **visual memory**, **executive function**, **complex attention** or **cognitive flexibility** (Figures 4.2, 4.3, 4.4, 4.6, 4.9 and 4.10). The absence of an interaction effect, combined with an absence of any main effects may mean that there was no added effect of stimulant medication for these CNSVS subtests. However, we observed significant interaction effects for the **neurocognitive index** ($F_{1,31}$=6.03, p=0.020), **processing speed** ($F_{1,31}$=5.61, p=0.024), and **psychomotor speed** ($F_{1,31}$=8.957, p=0.005) (Figures 4.1, 4.5, and 4.7). Tukey post hoc analyses for all significant interactions revealed that the ADHD group performed better when on medication compared to sessions when they were off their medication (d_{crit} values: neurocognitive index=4.91; processing speed=5.18; and psychomotor speed=4.06).

Balance Error Scoring System

We did not observe any significant interaction effects for **BESS** total score. However, we did observe a significant session main effect ($F_{1,32}$=5.17, p=0.030) (Figure 4.11). The ADHD and control group both performed better on the third testing session than they did on the second testing session. Although the ADHD group performed better on their medication than off their medication, the control group improved between the second and third testing session as well. This indicates that the increase in scores is likely due to a practice effect, as opposed to the medication.

Standardized Assessment of Concussion

We did not observe any significant interaction effects for **SAC** total score. However, we did observe a significant session main effect ($F_{1,32}$=16.000, p<0.005) (Figure 4.12).The

ADHD and control group both performed better on the third testing session than they did on the second testing session. Although the ADHD group performed better on their medication than off their medication, the control group improved between the second and third testing session as well. This indicates that the increase in scores is likely due to a practice effect, as opposed to the medication.

Research Question Two

Research question two examined the differences in scores on concussion assessment tools between the ADHD group when they were on their medication (session three) compared to matched controls under their third test condition. The same 2x2 repeated measures ANOVA models conducted for research question one were applied for this question.

CNS Vital Signs

As per above, we did not observe any significant group x session interactions or main effects for scores on ***composite memory***, ***verbal memory***, ***visual memory***, ***executive function***, ***complex attention*** or ***cognitive flexibility***. The absence of an interaction effect, combined with an absence of any main effects reflects that there was not a statistically significant difference between the two groups at session three on any of these subtests. While we observed significant interactions for the ***neurocognitive index***, ***processing speed*** and ***psychomotor speed***, post hoc analyses revealed no significant differences in scores between the ADHD and control group on the third testing session (Figures 4.1, 4.5 and 4.7).

Balance Error Scoring System

We did not observe any significant interaction or group main effects for the **BESS** Total Score (Figure 4.11). The absence of an interaction effect combined with the absence of

any group main effects means that there not a statistically significant difference between the two groups at session three for the BESS.

Standardized Assessment of Concussion

We did not observe any significant interaction or group main effects for the **SAC** total score (Figure 4.12). The absence of an interaction effect combined with the absence of any group main effects means that there is no statistically significant difference between the two groups at session three for the SAC.

Research Question Three

Research question three examined the differences in scores on concussion assessment tools between the ADHD group when they were off their medication (session two) compared to matched controls (session two). The same 2x2 repeated measures ANOVA models conducted for research questions one and two were applied for this question.

CNS Vital Signs

As previously described, we did not observe any significant group x session interactions or main effects for scores on *composite memory*, *verbal memory*, *visual memory*, *executive function*, *complex attention* or *cognitive flexibility* (Figures 4.2, 4.3, 4.4, 4.6, 4.9 and 4.10). The absence of an interaction effect, combined with an absence of any main effects may mean that there was no difference in scores between groups for these CNSVS subtests. However, we observed significant interaction effects for the *neurocognitive index* ($F_{1,31}$=6.03, p=0.020), *processing speed* ($F_{1,31}$=5.61, p=0.024), and *psychomotor speed* ($F_{1,31}$=8.957, p=0.005) (Figures 4.1, 4.5, and 4.7). Tukey post hoc analyses for all significant interactions revealed that the control group performed better than

the ADHD group on the second testing session (d_{crit} values: neurocognitive index=4.91; processing speed=5.18; and psychomotor speed=4.06).

Balance Error Scoring System

We did not observe any significant interaction or group main effects for the **BESS** total score (Figure 4.11). The absence of an interaction effect combined with the absence of any group main effects means that there is not a statistically significant difference between the two groups at session two for the BESS.

Standardized Assessment of Concussion

We did not observe any significant interaction or group main effects for the **SAC** total score (Figure 4.12). The absence of an interaction effect combined with the absence of any group main effects means that there is not a statistically significant difference between the two groups at session two for the SAC.

Research Question Four

Separate 2x2 repeated measures ANOVAs were also utilized to evaluate the differences in practice effect between individuals with ADHD compared to matched controls on commonly used clinical concussion measures, including the CNSVS, the BESS and the SAC between an initial taking of the tests (session one- ADHD: off medication) and a second taking of the tests (session two- ADHD: off medication).

CNS Vital Signs

We did not observe any significant group x session interactions or main effects for scores on ***composite memory, verbal memory***, ***visual memory***, ***processing speed, psychomotor speed,*** or ***reaction time.*** We did observe a significant interaction effects on ***composite memory*** ($F_{1,31}$=11.40, p=0.002) (Figure 4.14). Tukey post hoc analysis revealed

that the ADHD group performed better on their first testing session than they did on their second testing session (d_{crit}=6.37). In addition, we observed a significant session main effect for scores on the ***neurocognitive index*** ($F_{1,31}$=7.85, p=0.009), ***executive function*** ($F_{1,31}$=17.30, p<0.005), ***complex attention*** ($F_{1,31}$=5.46, p=0.026) and ***cognitive flexibility*** ($F_{1,31}$=17.24, p<0.005) (Figures 4.13, 4.18 and 4.22). In all cases, the scores of both the ADHD and control groups were higher on the second testing session, than on the first testing session, suggesting a significant practice effect existed for these subtests independent of group.

Balance Error Scoring System

We did not observe any significant group x session interactions or main effects for the **BESS** total score, suggesting there is no practice effect for either group

Standardized Assessment of Concussion

We observed a significant group x session interaction effect for the **SAC** total score ($F_{1,32}$=7.79, p=0.009)(Figure 4.24). Tukey post hoc analyses revealed that the control group performed better on the first testing session than they did on the second testing session (d_{crit}=0.81), suggesting there is not a practice effect. In addition, post hoc analyses revealed that the ADHD group performed statistically worse than the control group at both the first and second testing sessions, but closed the gap to some degree at the second session. Thus, to no surprise the results revealed a main effect for group ($F_{1,32}$=11.33, p=0.002), with the control group performing better than the ADHD group while off their medication.

Power and Effect Size

There was a relatively low sample size for this study, with somewhat low effect sizes. The effect sizes for each of the CNS Vital Signs subtests, BESS total score and SAC total score are presented in Table 4.5.

Summary of Results

The effect of ADHD on cognitive function has been widely researched; however the effect of ADHD on concussion measures is not as well understood. The most important result from our study is that individuals with ADHD perform better on select neurocognitive measures when on their prescribed stimulant medication. The ADHD subjects in our study presented with better processing speed, psychomotor speed and overall neurocognitive performance compared to when off medication (Research Question 1). The improved scores by the ADHD group in the absence of any improvement in the control group rules out the possibility that the improvement was due to a practice effect between session two and three. The stimulant medication appears to have had a positive effect on select cognitive domains and should be an important consideration for clinicians when administering cognitive tests.

Despite these improvements, there were no differences between the ADHD and control group on neurocognitive, balance or mental status performance when the ADHD group was on their medication (Research Question 2). However, the control group performed better than the un-medicated ADHD group on processing speed, psychomotor speed, and overall neurocognitive performance (Research Question 3). The ADHD group performed better on their first testing session than their second testing session on composite memory, while there was no change in scores in the control group. Conversely, the control group performed better on the first testing session on the *SAC*, while there was no difference

in the ADHD group (Research Question 4). Table 4.4 summarizes the statistically significant

findings by highlighting the concussion measures in which ADHD subjects demonstrated a

significant improvement while on medication.

Table 4.1: Demographic Information

Group	Age (Mean±SD)	Number of previous concussions	Symptom Scores-Testing Session 1 (Mean±SD)	Symptom Scores-Testing Session 2 (Mean±SD)	Symptom Scores-Testing Session 3 (Mean±SD)
ADHD	21.29±2.02	0.65±0.70	13.25±9.91	8.56±7.30	6.41±6.77
Control	21.29±2.05	0.65±0.70	4.12±4.97	5.81±8.52	6.35±11.05
Both	21.29±2.02	0.65±0.70	8.68±9.00	7.19±7.93	6.38±9.02

Table 4.2: Descriptive and statistical results for CNSVS, BESS and SAC between sessions two and three

Standard Scores	Group	Session 2 (S2) Mean	SD	Session 3 (S3) Mean	SD	Group* Session Interaction F (df) p value	Group Effect F (df) p value	Session Effect F (df) p value
Neurocognitive Index	ADHD	97.88	8.61	103.37	9.44	$F_{(1,31)}=6.03$ p=0.020**	$F_{(2,62)}=0.71$ p=0.405	$F_{(1,31)}=0.55$ p=0.462
	Control	105.00	13.74	102.06	11.40			
	Both	101.55		102.70				
Composite Memory Domain Score	ADHD	94.38	13.95	95.25	14.95	$F_{(1,31)}=3.54$ p=0.069	$F_{(1,31)}=2.95$ p=0.096	$F_{(1,31)}=2.52$ p=0.122
	Control	107.88	17.12	97.47	16.49			
	Both	101.33		96.39				
Verbal Memory Domain Score	ADHD	93.50	17.51	91.69	16.56	$F_{(1,31)}=0.60$ p=0.446	$F_{(1,31)}=3.43$ p=0.074	$F_{(1,31)}=1.52$ p=0.227
	Control	105.41	18.19	97.53	18.80			
	Both	99.64		94.70				
Visual Memory Domain Score	ADHD	97.31	13.72	99.56	12.53	$F_{(1,31)}=3.99$ p=0.055	$F_{(1,31)}=1.11$ p=0.299	$F_{(1,31)}=1.48$ p=0.234
	Control	107.29	14.50	98.06	15.66			
	Both	102.45		98.79				
Processing Speed Domain Score	ADHD	103.13	9.39	110.94	10.27	$F_{(1,31)}=5.61$ p=0.024**	$F_{(1,31)}=0.54$ p=0.467	$F_{(1,31)}=3.79$ p=0.061
	Control	110.65	17.34	109.88	15.44			
	Both	107.00		110.39				
Executive Function Domain Score	ADHD	100.38	11.68	100.56	11.68	$F_{(1,31)}=0.03$ p=0.855	$F_{(1,31)}=1.90$ p=0.178	$F_{(1,31)}=0.02$ p=0.897
	Control	107.65	14.20	107.65	14.20			
	Both	104.12		103.64				
Psychomotor Speed Domain Score	ADHD	101.19	8.04	109.75	10.34	$F_{(1,31)}=8.96$ p=0.005**	$F_{(1,31)}=0.27$ p=0.607	$F_{(1,31)}=9.21$ p=0.005*
	Control	107.82	17.00	107.88	16.91			
	Both	104.61		108.79				
Reaction Time Domain Score	ADHD	96.88	12.62	104.00	14.77	$F_{(1,31)}=3.08$ p=0.089	$F_{(1,31)}=0.06$ p=0.812	$F_{(1,31)}=2.44$ p=0.128
	Control	101.71	16.36	101.29	12.41			
	Both	99.36		102.61				
Complex Attention Domain Score	ADHD	98.12	16.44	103.00	11.63	$F_{(1,31)}=1.82$ p=0.187	$F_{(1,31)}=0.02$ p=0.904	$F_{(1,31)}=0.34$ P=0.566
	Control	100.94	17.14	99.00	17.15			
	Both	99.58		100.94				
Cognitive Flexibility Domain Score	ADHD	98.88	12.59	105.50	10.90	$F_{(1,31)}=3.43$ p=0.074	$F_{(1,31)}=0.65$ p=0.427	$F_{(1,31)}=1.11$ P=0.301
	Control	106.29	14.65	104.97	13.97			
	Both	102.70		104.97				
BESS Total Score	ADHD	10.71	3.53	9.29	2.39	$F_{(1,32)}=1.29$ p=0.264	$F_{(1,32)}=1.29$ p=0.264	$F_{(1,32)}=5.17$ p=0.030*
	Control	9.53	2.67	9.06	2.08			
	Both	10.12		9.18				
SAC Total Score	ADHD	27.18	1.59	28.18	1.43	$F_{(1,32)}<0.005$ p=1.00	$F_{(1,32)}=3.00$ p=0.093	$F_{(1,32)}=16.00$ p<0.005*
	Control	27.88	1.17	28.88	1.36			
	Both	27.88		28.88				

**Significant group x session interaction effect
* Significant main effect (group or session)

Table 4.3 Descriptive and statistical results for CNSVS, BESS and SAC between sessions one and two

	Group	Session 1 (S1)		Session 2 (S2)		Group* Session Interaction	Group Effect	Session Effect
		Mean	SD	Mean	SD	F (df) p	F (df) p	F (df) p
Neurocognitive Index	ADHD	94.31	10.74	97.88	8.61	$F_{(1,31)}=0.91$ p=0.348	$F_{(1,31)}=1.74$ p=0.197	$F_{(1,31)}=7.85$ p=0.009*
	Control	97.76	16.29	105.00	13.74			
	Both	96.09		101.55				
Composite Memory Domain Score	ADHD	104.56	10.15	94.38	13.95	$F_{(1,31)}=11.40$ p=0.002**	$F_{(1,31)}=1.73$ p=0.198	$F_{(1,31)}=1.41$ p=0.244
	Control	103.00	10.30	107.88	17.12			
	Both	103.76		101.33				
Verbal Memory Domain Score	ADHD	97.81	27.85	93.50	17.51	$F_{(1,31)}=1.24$ p=0.274	$F_{(1,31)}=1.49$ p=0.232	$F_{(1,31)}=0.05$ p=0.822
	Control	98.88	17.82	105.41	18.19			
	Both	98.36		99.64				
Visual Memory Domain Score	ADHD	103.63	9.98	97.31	13.72	$F_{(1,31)}=2.55$ p=0.120	$F_{(1,31)}=2.17$ p=0.151	$F_{(1,31)}=0.56$ p=0.461
	Control	105.00	15.07	107.29	14.50			
	Both	104.33		102.45				
Processing Speed Domain Score	ADHD	101.19	12.91	103.13	9.39	$F_{(1,31)}=0.53$ p=0.471	$F_{(1,31)}=2.11$ p=0.157	$F_{(1,31)}=3.41$ p=0.074
	Control	106.18	12.24	110.65	17.34			
	Both	103.76		107.00				
Executive Function Domain Score	ADHD	91.56	15.17	100.38	11.68	$F_{(1,31)}=0.13$ p=0.723	$F_{(1,31)}=1.74$ p=0.196	$F_{(1,31)}=17.30$ p<0.005*
	Control	97.18	19.66	107.65	14.20			
	Both	94.45		104.12				
Psychomotor Speed Domain Score	ADHD	100.25	8.42	101.19	8.04	$F_{(1,31)}=0.94$ p=0.341	$F_{(1,31)}=0.37$ p=0.550	$F_{(1,31)}=1.51$ p=0.229
	Control	99.88	29.32	107.82	17.00			
	Both	100.06		104.61				
Reaction Time Domain Score	ADHD	97.56	14.69	96.88	12.62	$F_{(1,31)}=0.01$ p=0.967	$F_{(1,31)}=3.89$ p=0.026** ADHD>Control	$F_{(1,31)}=2.07$ p=0.160
	Control	92.35	18.48	101.71	16.36			
	Both	94.88		99.36				
Complex Attention Domain Score	ADHD	80.25	34.61	98.12	16.44	$F_{(1,31)}=0.49$ p=0.490	$F_{(1,31)}=0.79$ p=0.380	$F_{(1,31)}=5.46$ p=0.026
	Control	91.29	37.01	100.94	17.14			
	Both	85.94		99.58				
Cognitive Flexibility Domain Score	ADHD	88.75	16.12	98.88	12.59	$F_{(1,31)}<0.005$ p=0.973	$F_{(1,31)}=2.04$ p=0.163	$F_{(1,31)}=17.24$ p<0.005*
	Control	96.00	20.72	106.29	14.65			
	Both	92.48		102.70				
BESS Total Score	ADHD	12.35	3.46	10.71	3.53	$F_{(1,32)}=0.78$ p=0.385	$F_{(1,32)}=2.32$ p=0.138	$F_{(1,32)}=10.42$ p=0.003*
	Control	10.47	2.85	9.53	2.67			
	Both							
SAC Total Score	ADHD	26.59	2.29	27.18	1.59	$F_{(1,32)}=7.79$ p=0.009**	$F_{(1,32)}=11.33$ p=0.002*	$F_{(1,32)}=0.52$ p=0.475
	Control	28.88	0.60	27.88	1.16			

**Significant group x session interaction effect

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Table 4.4 Results summary table

Research Question	Neurocognitive Index	Composite Memory	Processing Speed	Psychomotor Speed	SAC Total Score
1: ADHD **on** medication vs. ADHD **off** medication	On medication > Off medication		On medication > Off medication	On medication > Off medication	On medication > Off medication
2: ADHD **on** medication vs. controls					
3: ADHD **off** medication vs. controls	Control > ADHD		Control > ADHD	Control > ADHD	
4: Practice effect between ADHD off medication and controls		ADHD Session 1> ADHD Session 2			Control Session 1 > Control Session 2

No significant results were observed for Verbal Memory, Visual Memory, Executive Function, Reaction Time, Complex Attention, Cognitive Flexibility, or BESS Total Score, and are thus emitted from this table.

Table 4.5 Effect sizes calculated using Cohen's d

Domain	Effect Size (Cohen's d) ADHD S3: ADHD S2	Effect Size (Cohen's d) Control S3:ADHD S3
NCI	0.61	0.13
Composite Memory	0.06	0.14
Verbal Memory	1.12	0.33
Visual Memory	0.03	0.11
Processing Speed	0.79	0.08
Executive Function	0.015	0.55
Psychomotor Speed	0.92	0.13
Reaction Time	0.30	0.20
Complex Attention	0.34	0.04
Cognitive Flexibility	0.56	0
BESS Total Score	0.47	0.10
SAC Total Score	0.66	0.50

(S=testing session)

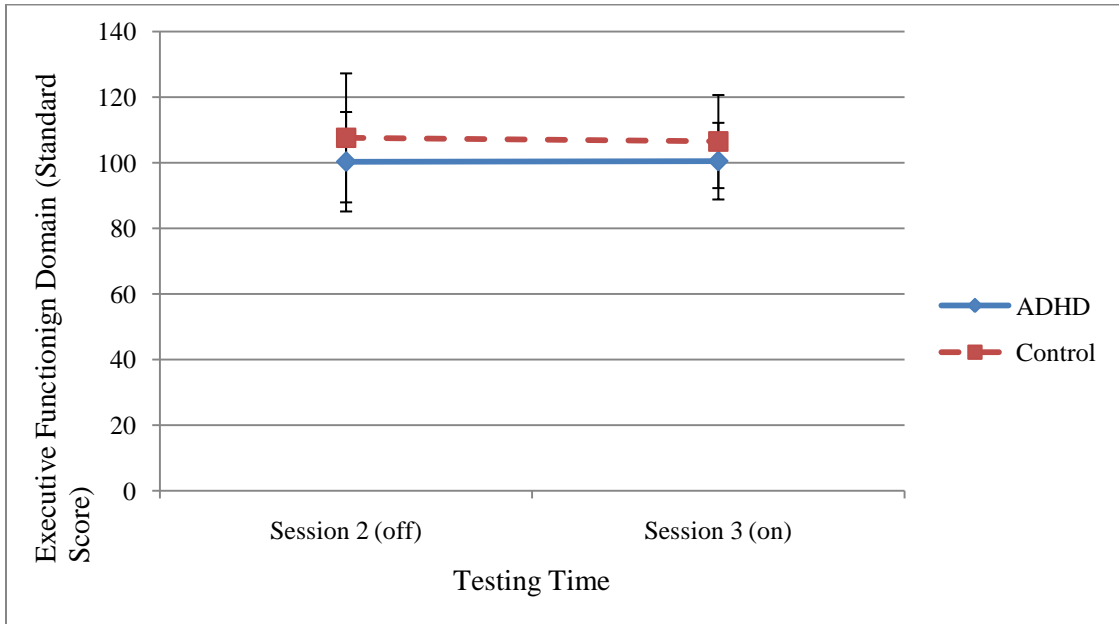**Figure 4.1. ADHD vs. Control on Neurocognitive Index- NCI (CNSVS)**
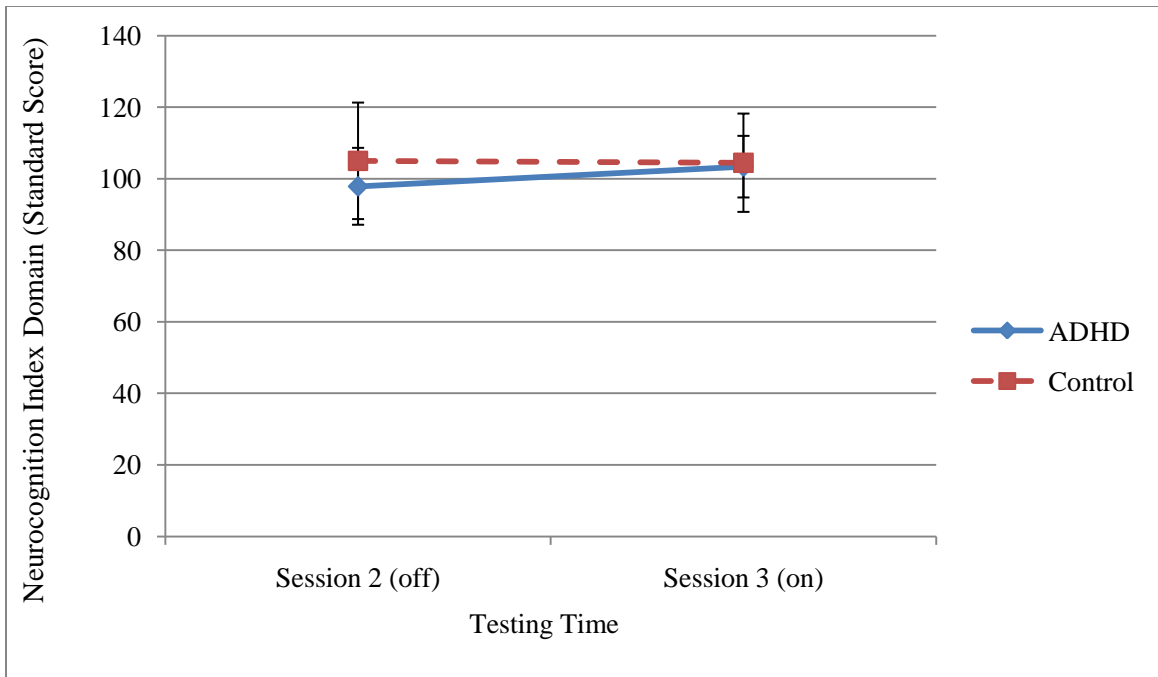
*Significant interaction effect
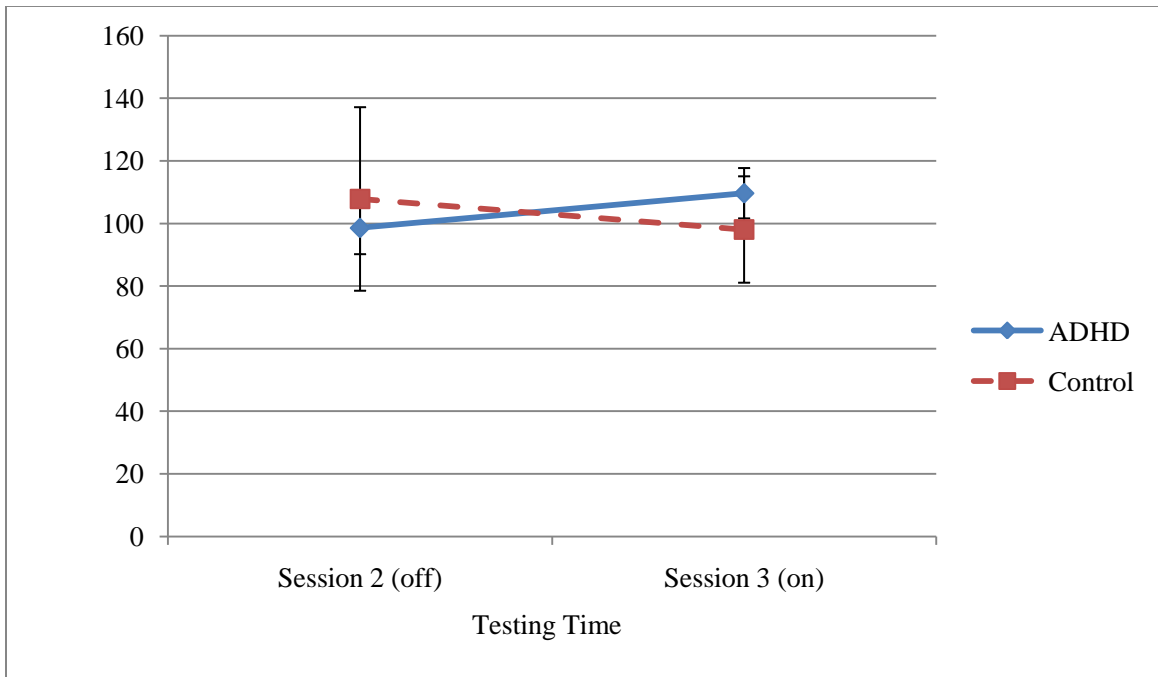 ADHD Session 3 > ADHD Session 2 (Research Question 1)
  Control Session 2 > ADHD Session 2 (Research Question 3)

Figure 4.2. ADHD vs. Control on Composite Memory Domain (CNSVS)
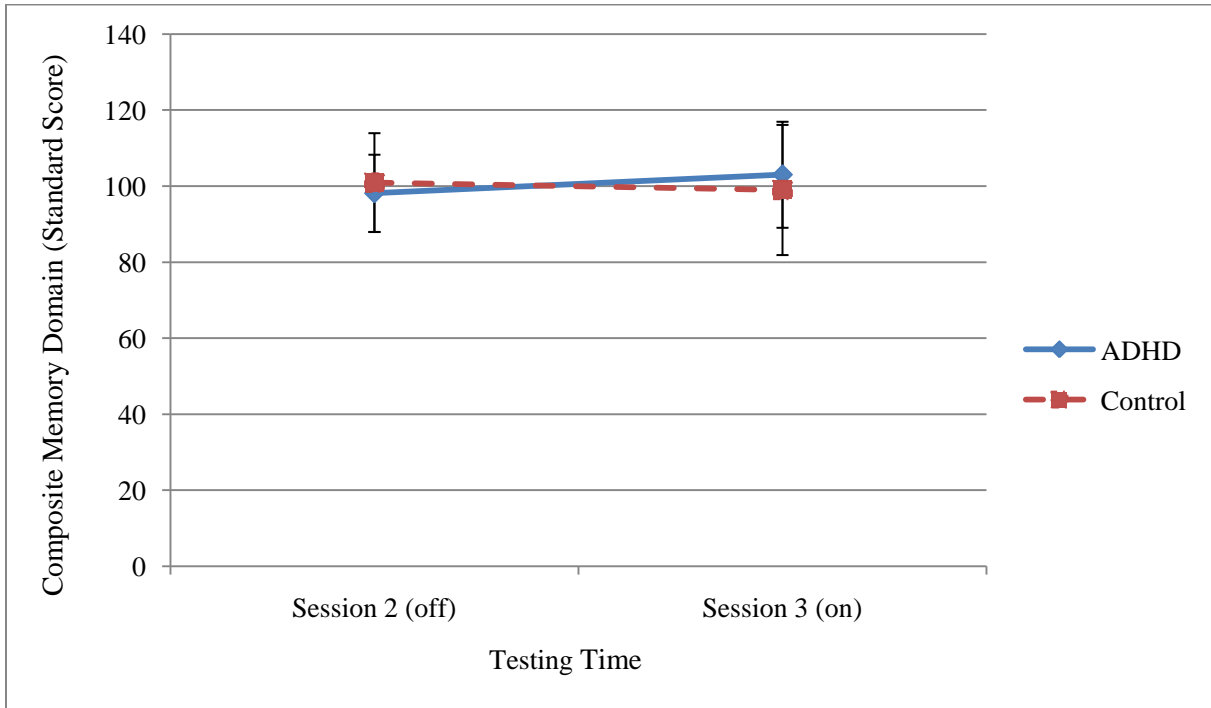
No significant effects were observed.

Figure 4.3. ADHD vs. Control on Verbal Memory Domain (CNSVS)
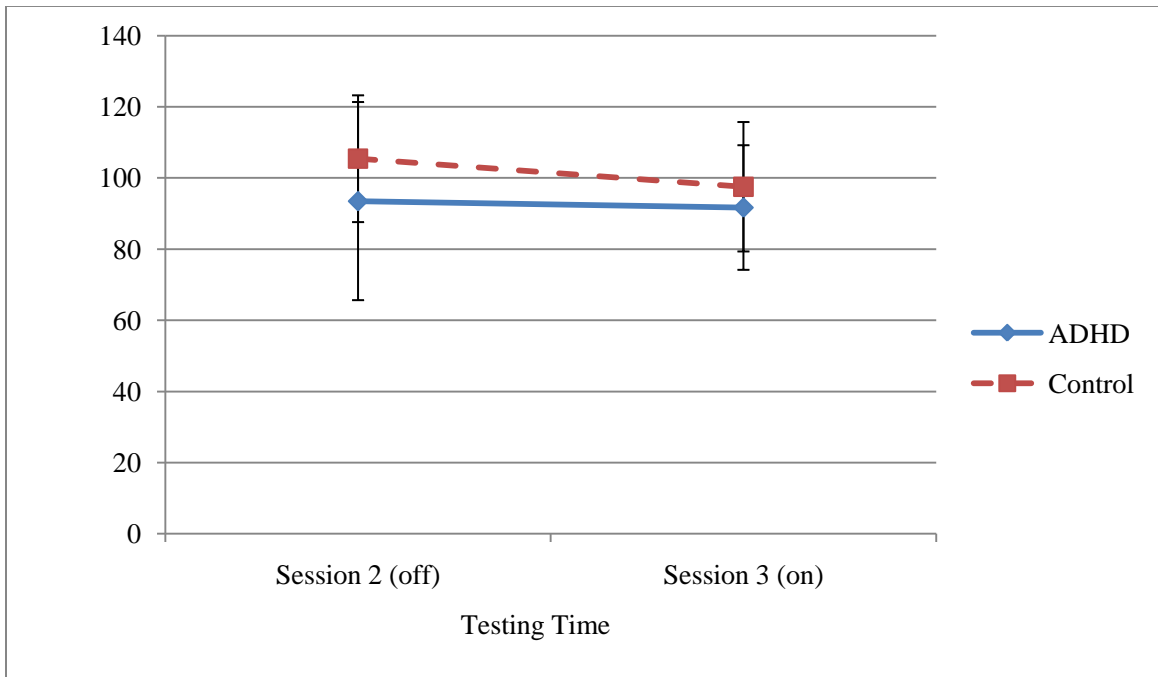
No significant effects were observed.

Figure 4.4. ADHD vs. Control on Visual Memory Domain (CNSVS)
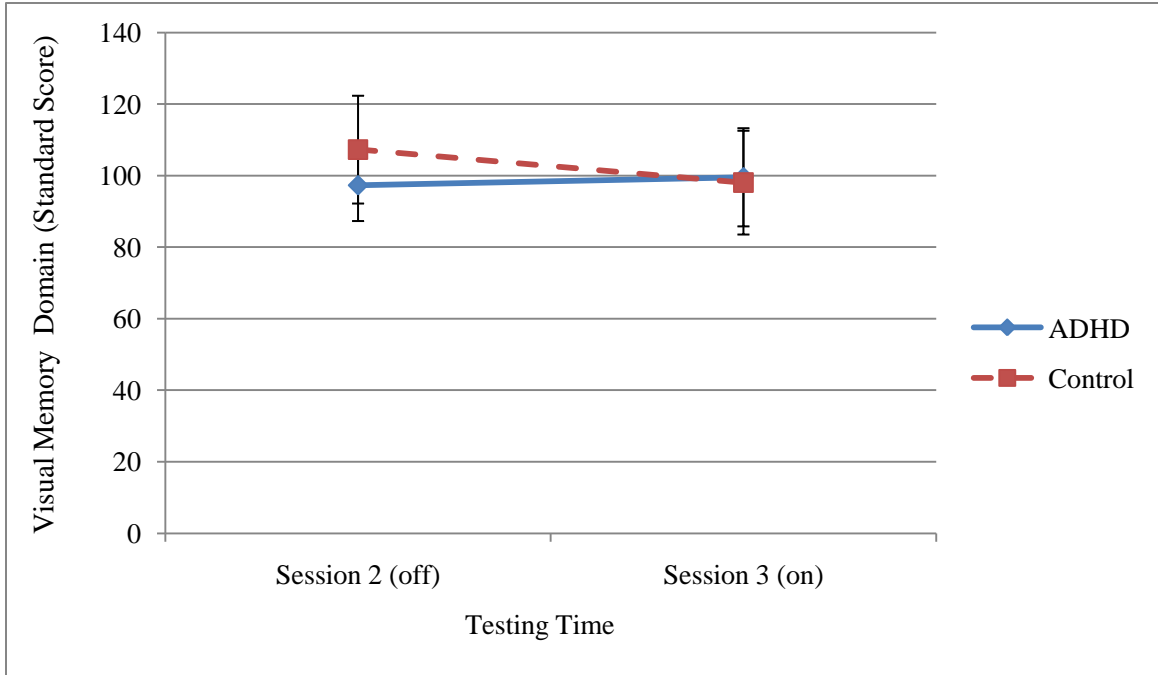
No significant effects were observed.

**Figure 4.5. ADHD vs. Control on Processing Speed Domain (CNSVS)**
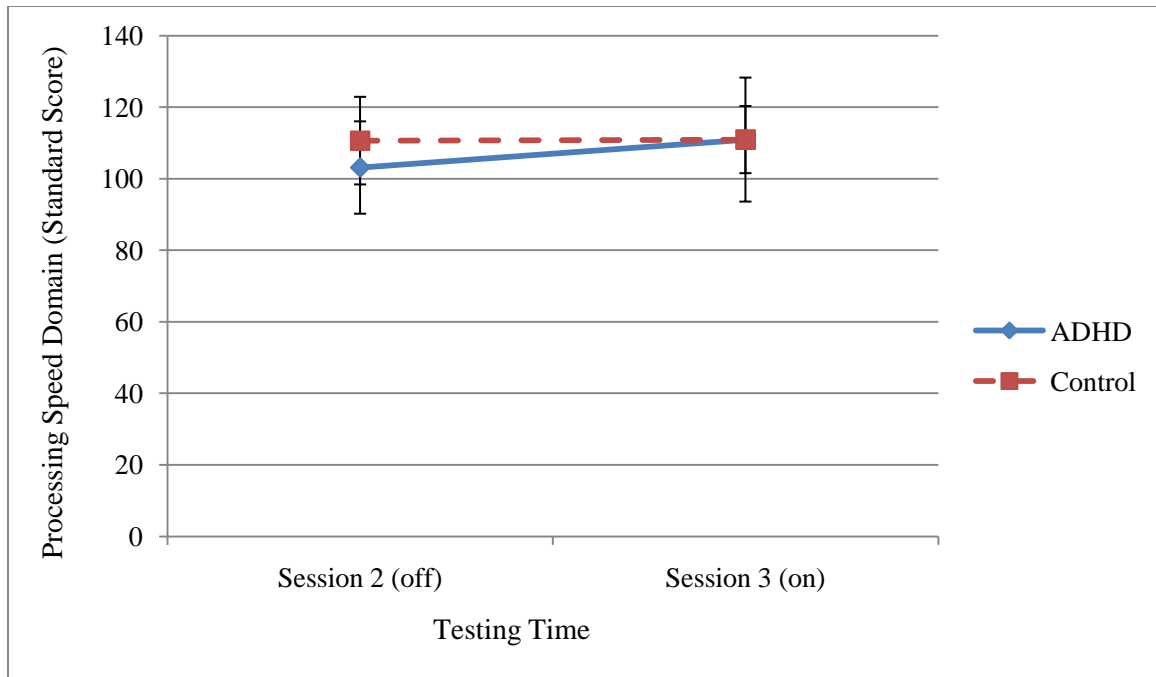
*Significant interaction effect
  ADHD Session 3 > ADHD Session 2 (Research Question 1)
  Control Session 2 > ADHD Session 2 (Research Question 3)

Figure 4.6. ADHD vs. Control on Executive Functioning Domain (CNSVS)

No significant effects were observed.

Figure 4.7. ADHD vs. Control on Psychomotor Speed Domain (CNSVS)

*Significant interaction effect
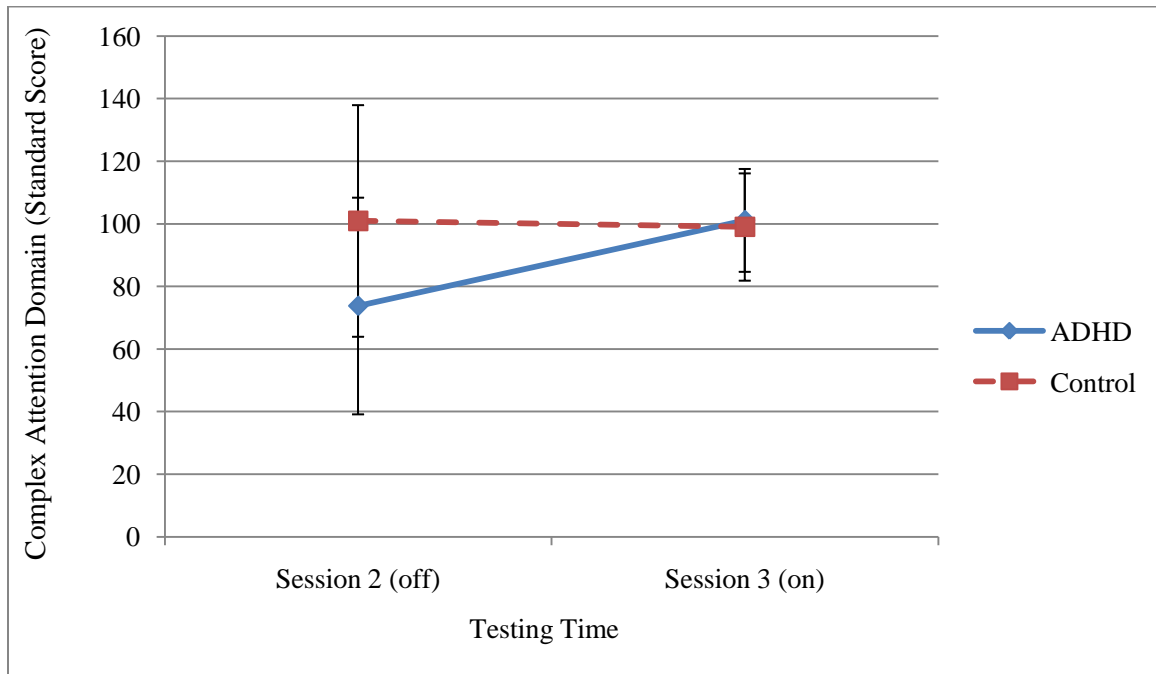 ADHD Session 3 > ADHD Session 2 (Research Question 1)
 Control Session 2 > ADHD Session 2 (Research Question 3)

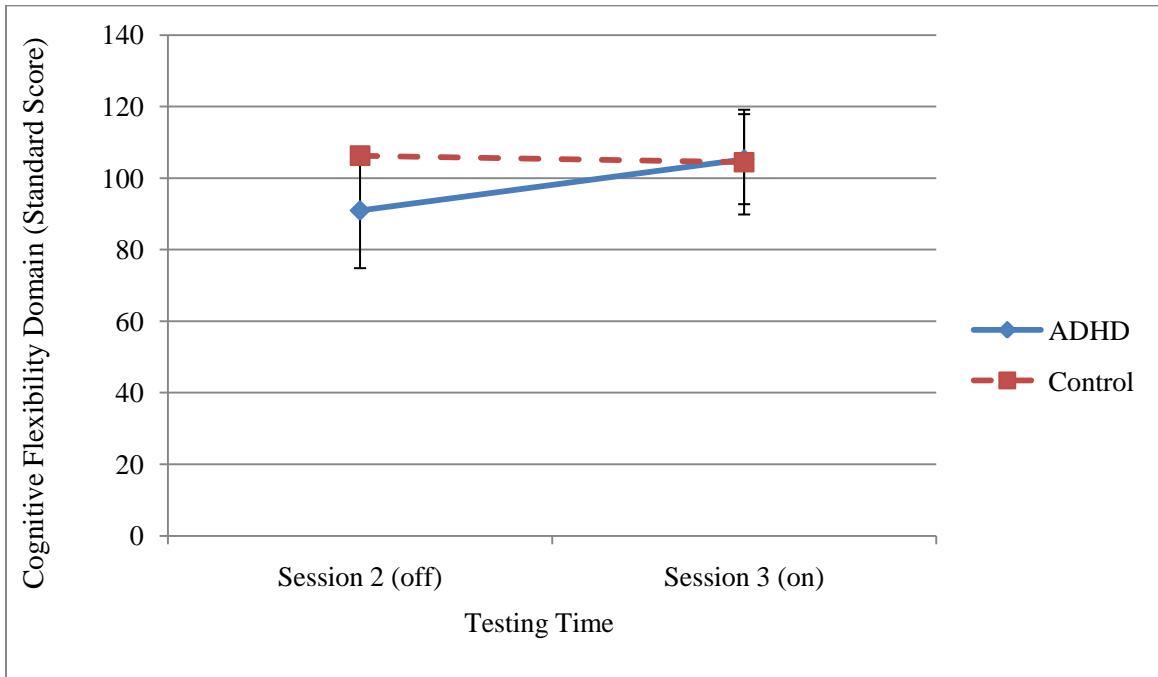**Figure 4.8. ADHD vs. Control on Reaction Time Domain (CNSVS)**
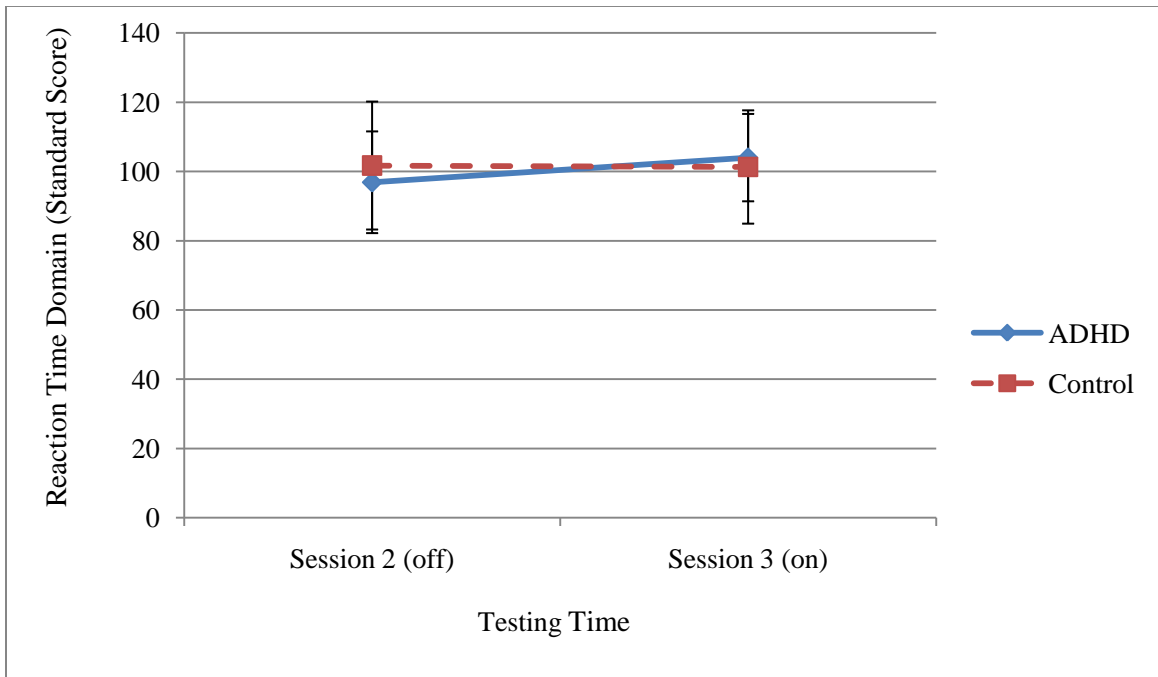
No significant effects were observed.

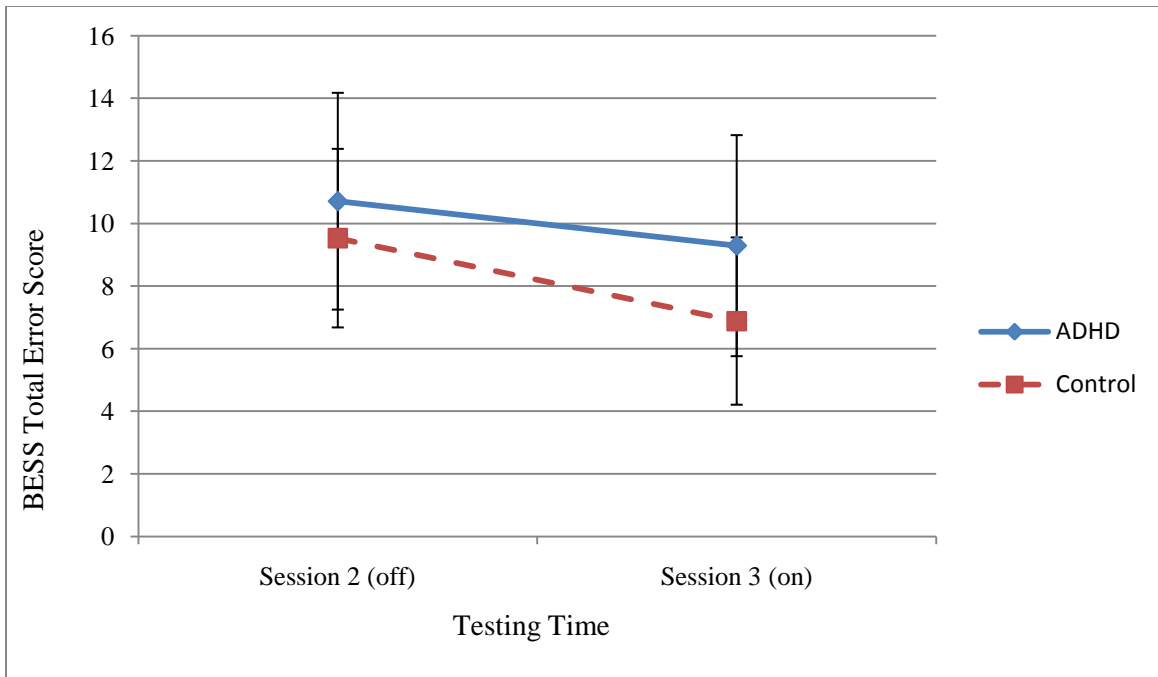**Figure 4.9. ADHD vs. Control on Complex Attention Domain (CNSVS)**

No significant effects were observed.

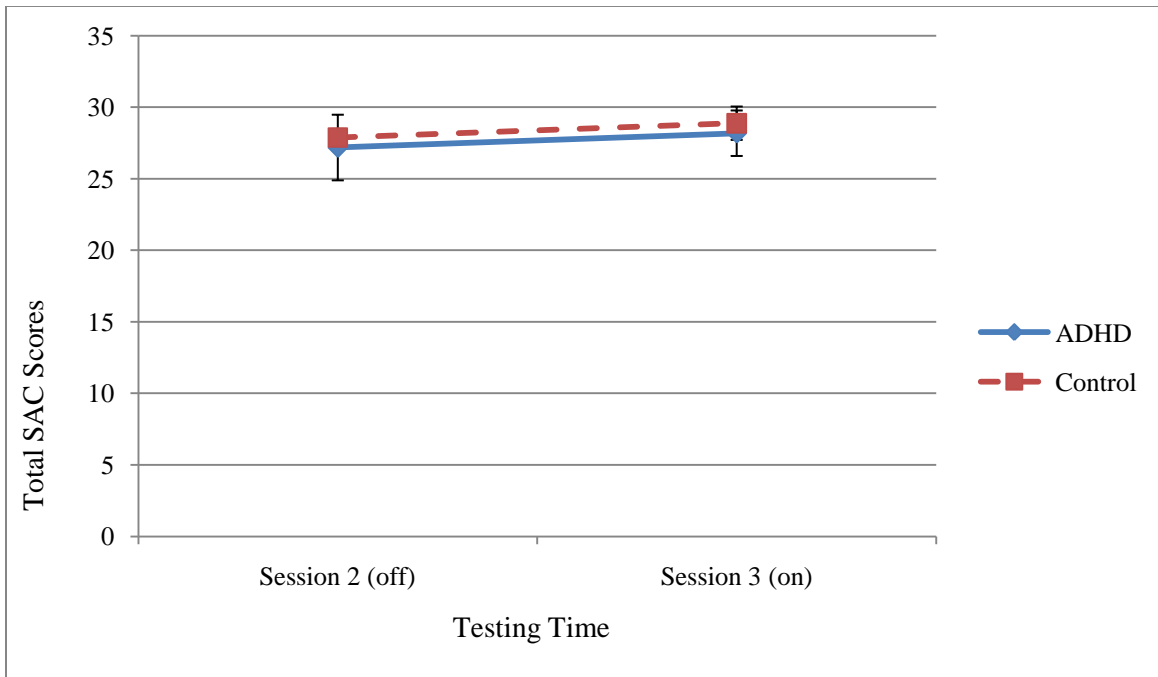**Figure 4.10. ADHD vs. Control on Cognitive Flexibility (CNSVS)**

No significant effects were observed.

Figure 4.11. ADHD vs. Control on Total Error Score (BESS)

No significant effects were observed.

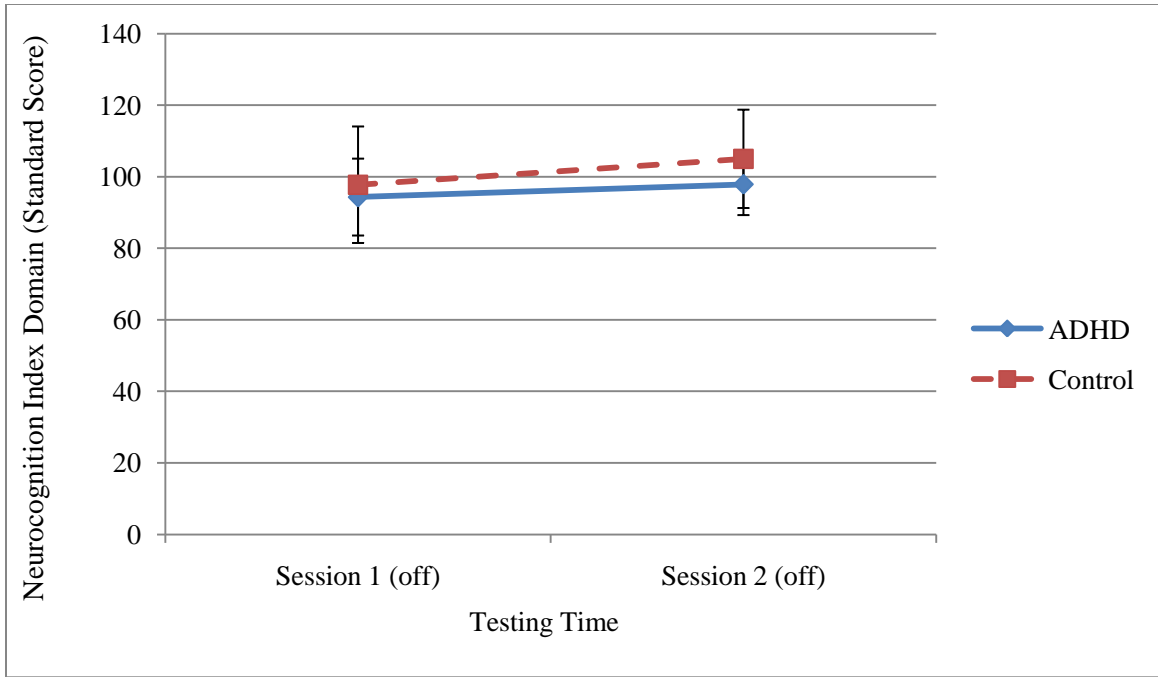**Figure 4.12. ADHD vs. Control on Total Score (SAC)**

*Significant session main effect ($F_{1,32}=16.00$, p<0.005).
Control S3 > Control S2
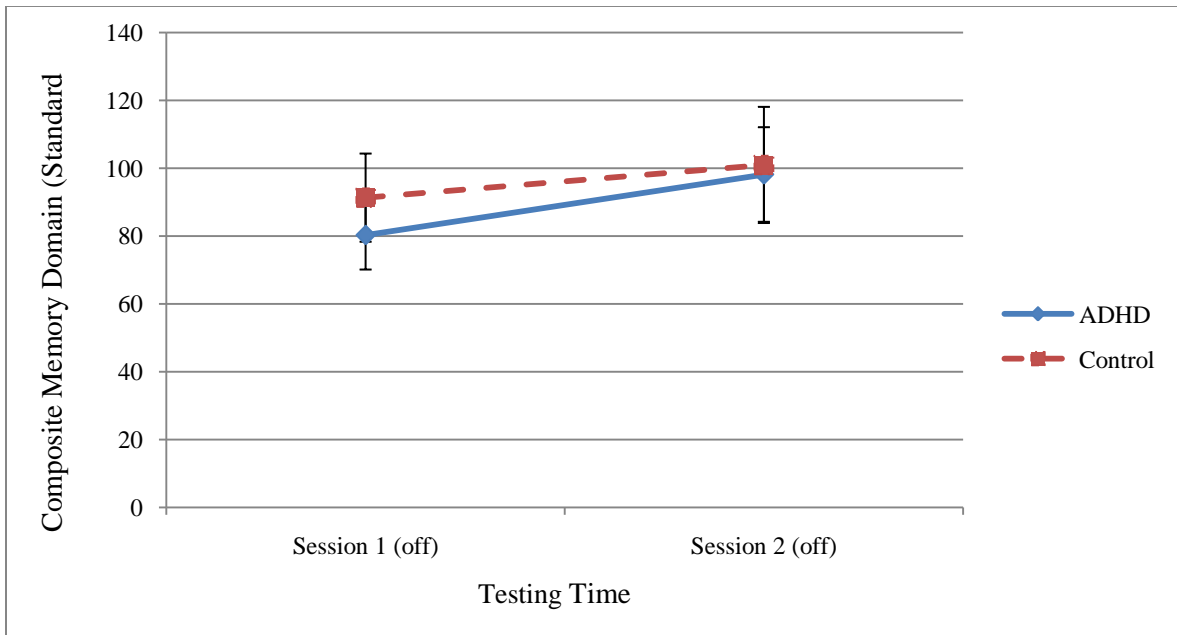ADHD S3> ADHD S2

Figure 4.13. ADHD vs. Control on Neurocognitive Index- NCI (CNSVS)

*Significant session main effect

Figure 4.14. ADHD vs. Control on Composite Memory Domain (CNSVS)

*Significant interaction effect
ADHD Session 1 > ADHD Session 2 (Research Question 4)

Figure 4.15. ADHD vs. Control on Verbal Memory Domain (CNSVS)
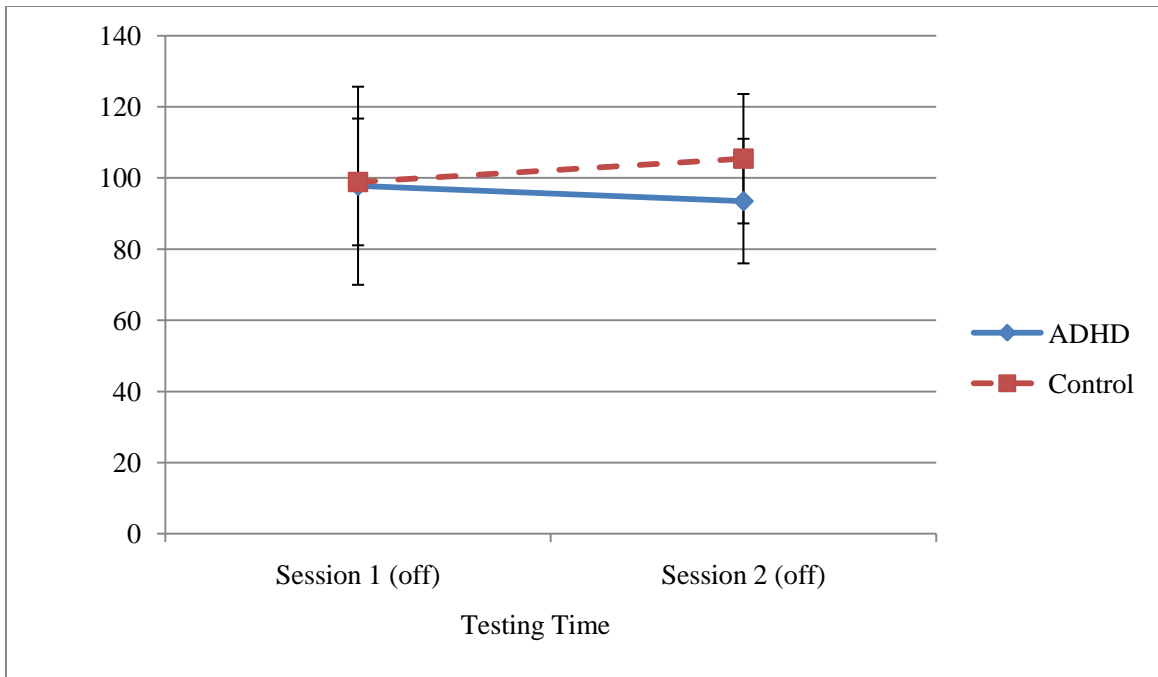
No significant effects were observed.

Figure 4.16. ADHD vs. Control on Visual Memory Domain (CNSVS)
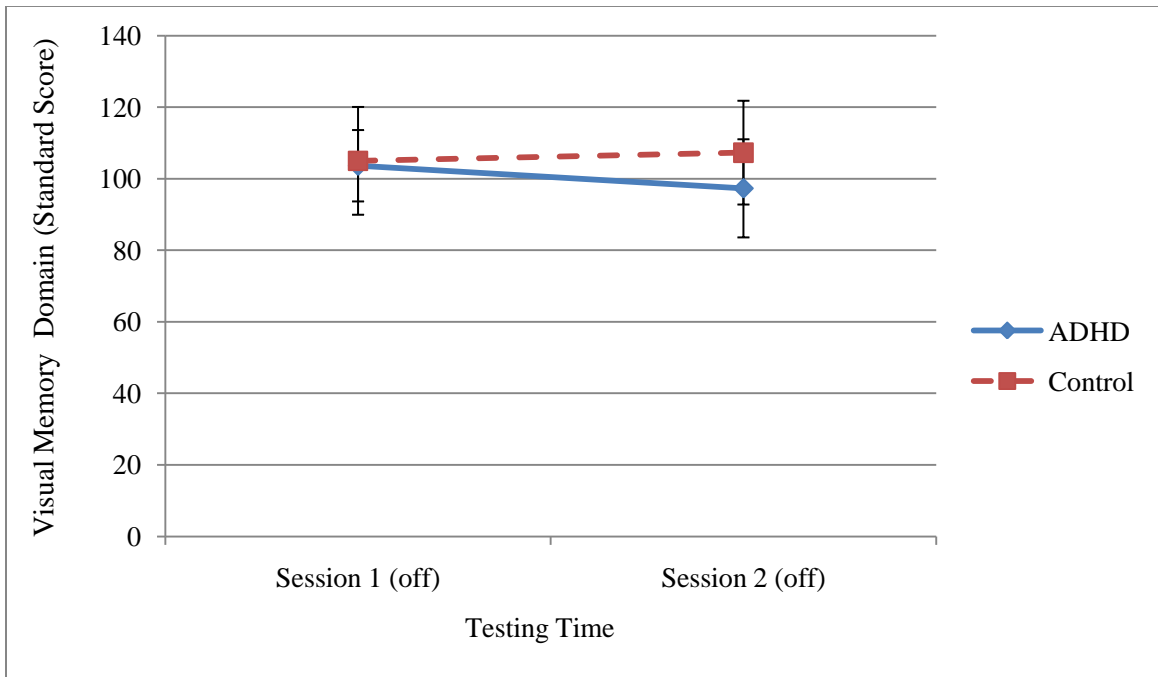
No significant effects were observed.

Figure 4.17. ADHD vs. Control on Processing Speed Domain (CNSVS)

No significant effects were observed.

Figure 4.18. ADHD vs. Control on Executive Functioning Domain (CNSVS)
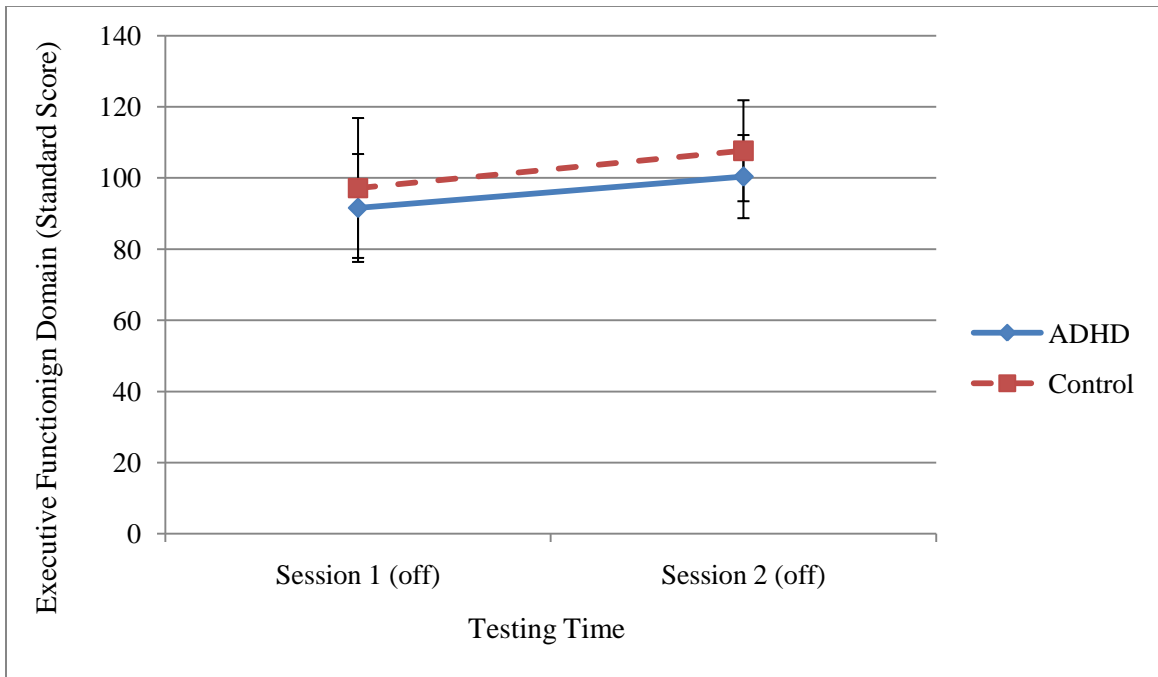
*Significant session main effect

Figure 4.19. ADHD vs. Control on Psychomotor Speed Domain (CNSVS)
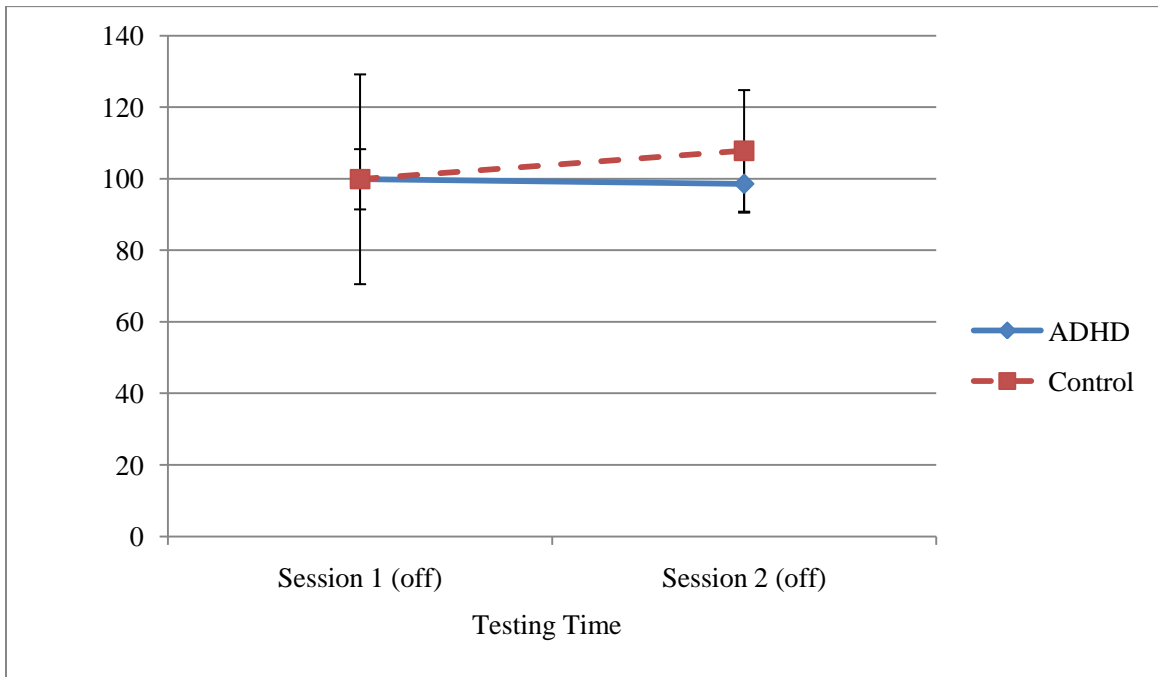
No significant effects were observed.

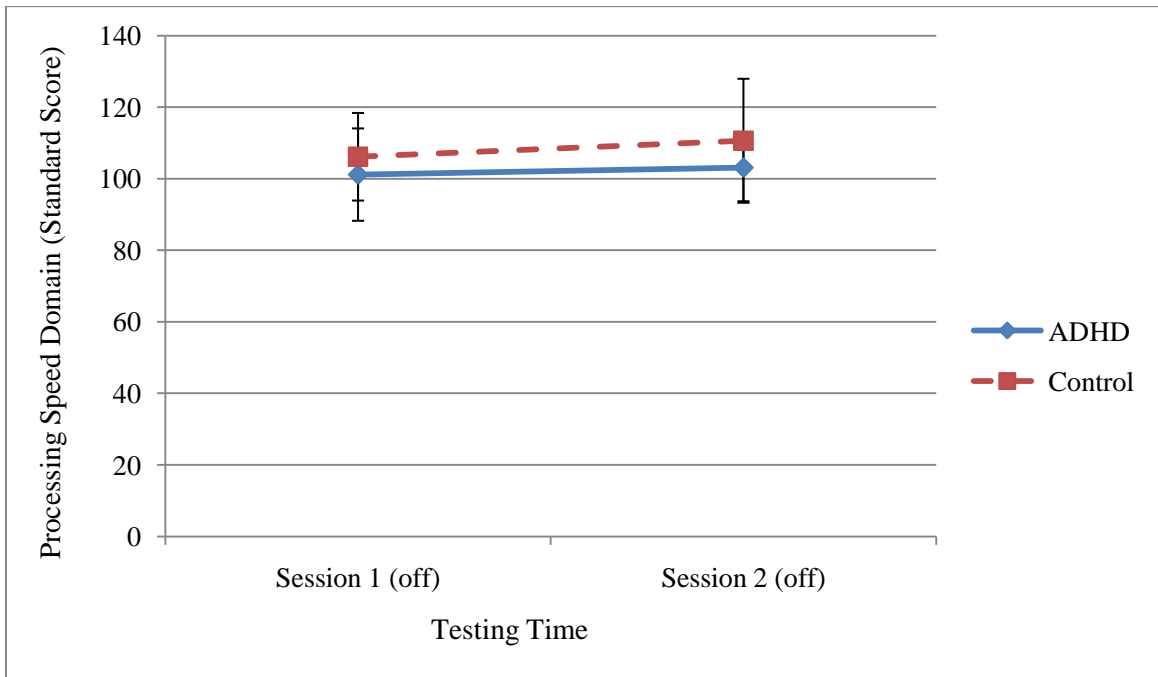**Figure 4.20. ADHD vs. Control on Reaction Time Domain (CNSVS)**

No significant effects were observed.

Figure 4.21. ADHD vs. Control on Complex Attention Domain (CNSVS)
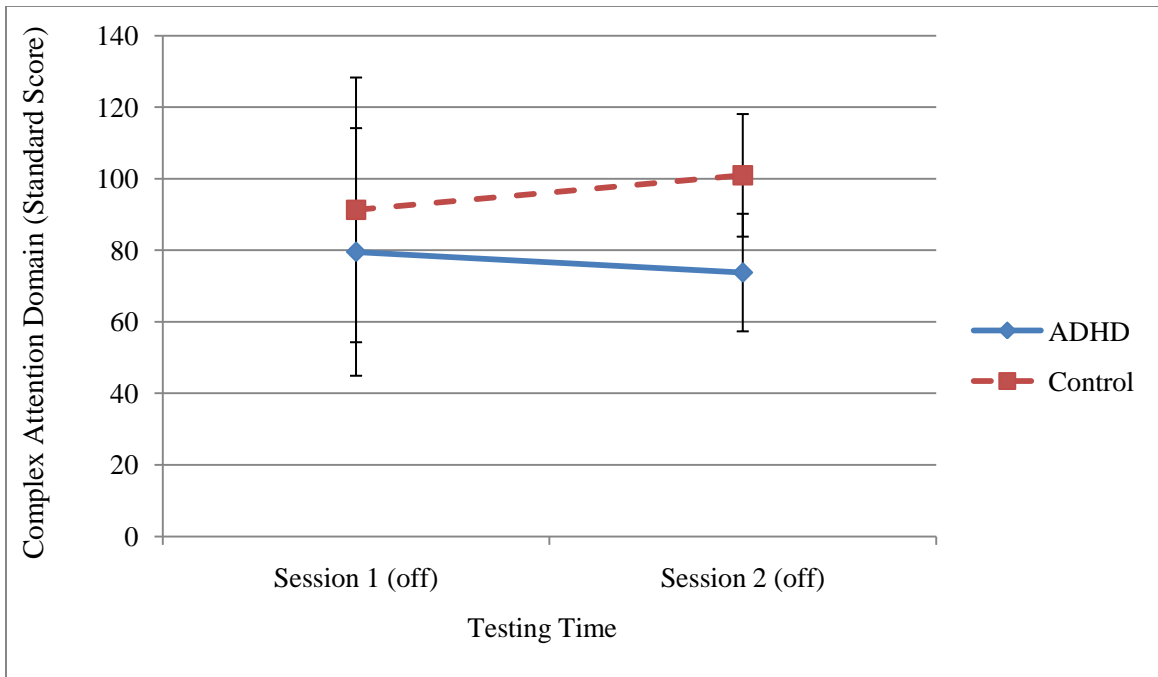
No significant effects were observed.

Figure 4.22. ADHD vs. Control on Cognitive Flexibility (CNSVS)
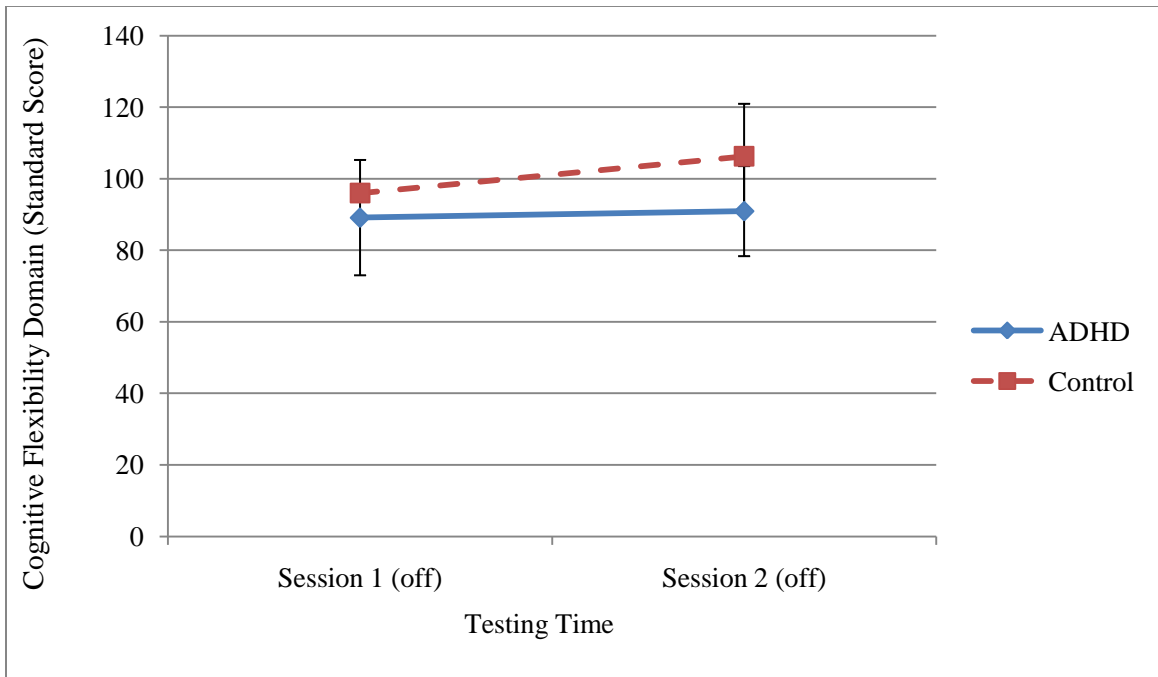
*Significant session main effect

Figure 4.23. ADHD vs. Control on Total Error Score (BESS)
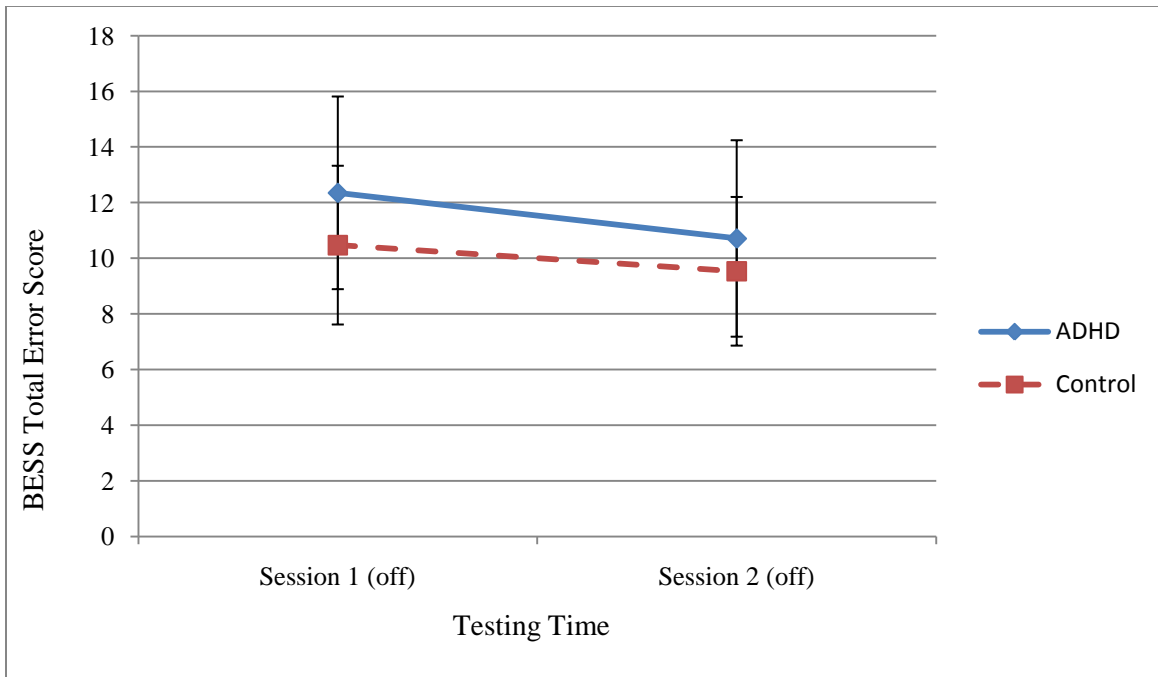
No significant effects were observed.
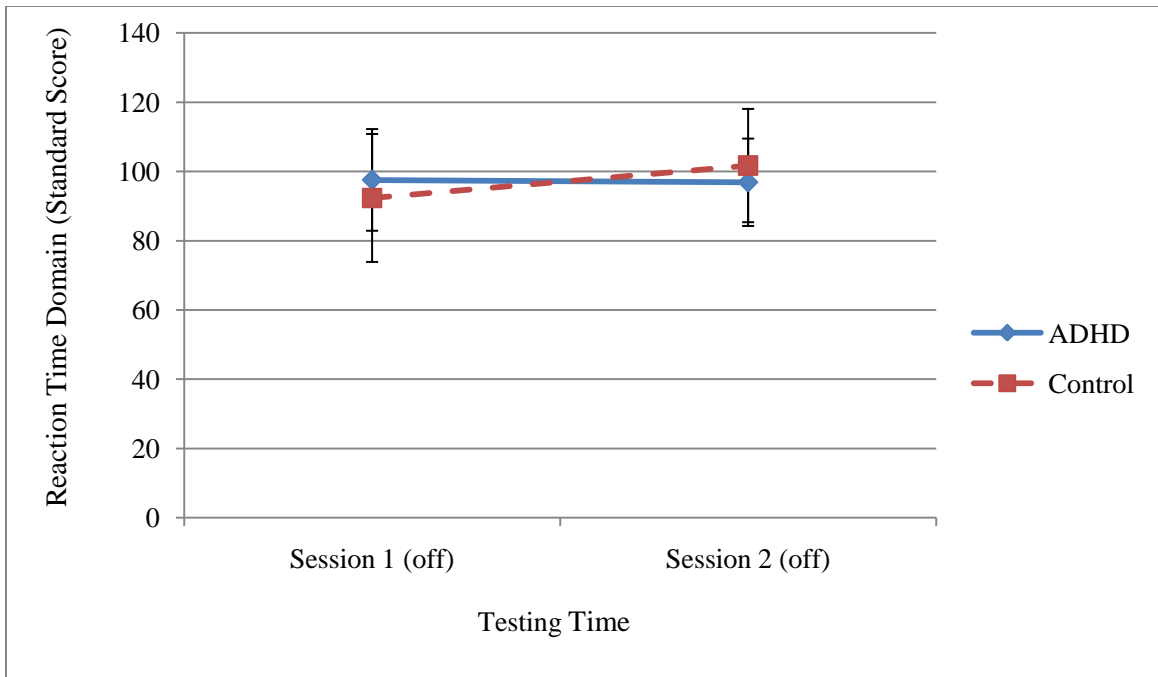
Figure 4.24. ADHD vs. Control on Total Score (SAC)
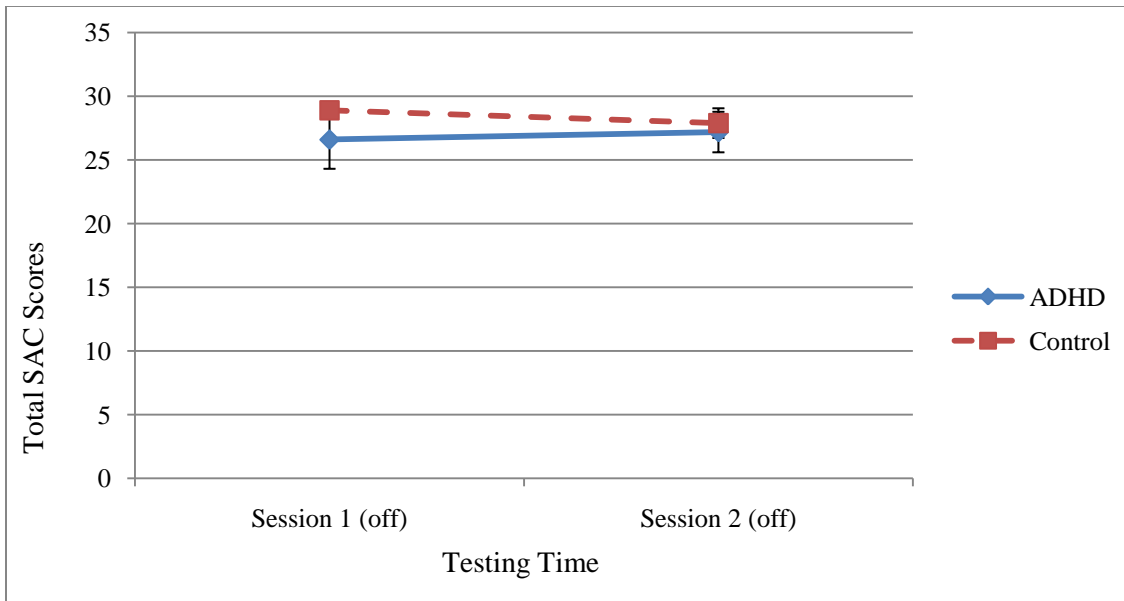
*Significant interaction effect ($F_{1,32}=7.79$, $p=0.009$)
  Control session 1 > Control session 2
  Control session 1 > ADHD session 1
  Control session 2 > ADHD session 2

CHAPTER V

DISCUSSION

The effect of ADHD on cognitive function has been widely researched; however, the effect of ADHD on concussion measures is not as well understood. The most important result from our study is that individuals with ADHD perform better on select neurocognitive measures when on their prescribed stimulant medication.

Effects of Stimulant Medications

We expected to see the medications have a positive effect on overall neurocognitive functioning by increasing arousal of the Central Nervous System (CNS). The theory behind stimulant medications is that they increase arousal and alertness of the (CNS) through stimulation of norepinephrine and dopamine (Volkow, Gur et al. 1998; Vaughn, et al., 2011; Rowe, Robinson & Gordon, 2005). One study found that stimulants suppress the locus coeruleus, which reduces stimulation of the thalamic reticular nucleus, ultimately improving cortical arousal (Rowe, Robinson & Gordon, 2005)**.** Therefore, it is not surprising that the ADHD group improved on overall neurocognitive functioning while medicated. In fact, a study by Riordan et al, also found that a stimulant medication improved overall performance on a battery of neuropsychological tests including measures of motor speed, processing speed and distractibility in an adult ADHD group (Riordan, et al., 1999). Furthermore, we expected to observe positive effects of medication on both the processing speed and psychomotor speed scores, because they are measures of attention and focused concentration (or distractibility) and

stimulant medications have been shown to improve concentration and attention (Hickey and Fricker 1999).

We expected to observe a positive effect of medication on all measures of CNSVS, but did not observe an effect of medication on measures of composite memory, verbal memory, visual memory, reaction time, complex attention or cognitive flexibility. In addition, we expected to see a positive effect of medication on the BESS and SAC. A probable reason the medication did affect many factors of the CNSVS, BESS or SAC is because the ADHD group did not have deficits in these categories compared to a control group, when they were off their medication. Although previous studies have found stimulant medications to have an effect on some of domains of CNS Vital Signs, it has also been observed that as individuals with ADHD age and mature from the adolescent population to adulthood, their test scores normalize (Gualtieri and Johnson 2005). Therefore, a collegiate population who is likely to be intelligent and motivated and have their ADHD treatment under control is more likely to have normal neurocognitive, balance and mental status scores compared to an adolescent or child population.

Our study suggests that although stimulant medication did not appear to improve balance or mental status, it did affect some neuropsychological components, including overall neurocognitive performance, processing speed and psychomotor speed. Based on the results of our study, ADHD athletes should complete both their baseline and post-injury tests on their prescribed stimulant medications. The majority of stimulant medications are prescribed to be taken on a daily basis. This study observed that when the ADHD participants were on their medication, there were no differences between their scores and the control group's scores. However, when the ADHD group was off their medication, there were difference in neurocognitive performance, processing speed and psychomotor speed.

In some cases, it may not be feasible for the individual to be on their medication for both the baseline and post injury testing. For example, in some settings, it may be too difficult to notify all ADHD athletes who are prescribed a stimulant medication to make sure they take their medication prior to the testing session. When this is the case, it could be helpful to document the medication status of the athlete stay constant across sessions. Questions such as: "Have you ever been diagnosed with attentional deficit hyperactivity disorder (ADHD), attentional deficit disorder (ADD) or any other learning disability?", "If so, when were you diagnosed?", "Do you currently take any type of medication for the treatment of ADHD, ADD or other learning disability?", "When did you first start taking the medication you are currently taking?", "What type of medication are you on and what is your dose?", "How often do you take your medication?", "Do you think your medication works?" and "How long has it been since you last took your prescribed medication?", should be added to the standard battery of concussion assessment tools. This will allow for a better interpretation of post-injury scores, because it will allow the clinician to know if the testing sessions were conducted under the same or similar medication statuses. If testing sessions are held under different medication statuses, test scores should be carefully interpreted as medication status can affect some of the scores.

Attention Deficit Hyperactivity Disorder (ADHD)

We observed differences in scores on the NCI, processing speed and psychomotor speed portions of CNS Vital Signs between the control group and the ADHD group, when the ADHD group was off their medication. On all three domains, the control group performed better than the ADHD group. There was no significant difference between the groups on measures of balance or mental status. While we initially hypothesized that the control group would perform better than the ADHD group on all measures of neurocognitive functioning, balance and mental

status, it is plausible that the ADHD group may not be impaired with certain types of memory, or balance. Most studies that showed memory impairment within the ADHD population studied working memory (which involves retaining and manipulating information for several seconds), or recall memory, while CNS Vital Signs assesses recognition memory (Gropper and Tannock 2009; Valera, Brown et al. 2009). It is likely that recognition memory is easier for the ADHD population and therefore they are able to perform similarly to a control group on the verbal and visual memory measures.

However, it is interesting that there were no significant differences between the groups on measures of reaction time, complex attention and cognitive flexibility, because they have been found to be influenced by ADHD (Gualtieri and Johnson 2005). It is possible that changes were not seen in this group, because individuals with ADHD who are able to perform academically at the collegiate level may have a milder form of the disorder (Wilmshurst and Peele). In addition, it is possible that compared to the adolescent population, where the cognitive and balance deficits are typically seen, the collegiate population likely tends to be more mature and is more likely to have found the best treatment for their disorder. It has been observed that individuals with ADHD experience a decrease in both the frequency and severity of symptoms as they age (Hart, et al. 1995). Since differences between the adolescent and adult ADHD population has been shown, it has even been suggested that age-specific assessments of ADHD should be considered (Ramtekkar, Reiersen et al.). Furthermore, a study by Schwartz et al. found that there was no difference between scores on Stroop interference tasks between an ADHD and age matched controls, and in our study the scores from the Stroop interference tasks make up part of the scores for reaction time, complex attention and cognitive flexibility scores (Schwartz, Sharma et al. 2009).

Our study indicates that when ADHD individuals are on their stimulant medication, their scores are comparable to those of matched controls. This provides an important implication for serial testing of ADHD athletes. If individuals with ADHD are comparable to matched controls, when they are on their stimulant medications, then it is desirable that individuals with ADHD to take their stimulant medication prior to baseline and post-injury testing. In the case where an athlete with ADHD sustains a concussion, but does not have a baseline measure, the team physician and athletic trainer should instruct the athlete to take their stimulant medication prior to follow-up testing to allow for comparisons with normative data.

Recent recommendations suggest that baseline testing on neurocognitive, postural control, and symptomatology measures be completed prior to sport exposure for all athletes, so that appropriate comparisons can be made post-injury. Our study suggests that both ADHD and stimulant medications affect scores on concussion assessment tools. Clinicians should make an effort to identify athletes with ADHD prior to concussion baseline evaluation and treat these athletes with special care to ensure quality baseline scores.

Practice Effects

A secondary aim of our study was to examine differences in practice effects between the control group and the ADHD group when they were off their medication. We observed that the ADHD group performed better on the composite memory portion of CNSVS on their first testing session than their second testing session, while there was no significant difference between testing sessions in the control group. Additionally, the control group performed better on the first testing session than on the second testing session for the SAC total score, while there was no significant difference between testing sessions in the ADHD group. CNSVS has been shown to be both valid and reliable (Gualtieri and Johnson 2006). However, there may be differences in

test-retest reliability between the ADHD and control population. We hypothesized that the control group may benefit from a practice effect between the first and second testing session, while the ADHD group might not. Our study suggests that the ADHD group declined in performance between the first and second testing session on the composite memory portion of CNSVS. This could be due to the fact that the ADHD group performed better on the first testing session, due to the novelty effect, or the excitement associated with completing a task for the first time, while the task was not new during the second testing session and they knew that they would have to sustain their attention for a long period of time (Poppenk, Walia et al. 2008). Composite memory was likely affected because the score is a combination of scores on both verbal and visual memory, in which tasks are repeated the end of the testing battery. Therefore, they require attention over an extended period of time.

Another interesting finding is that the control group had decreased scores between their first and second testing session on the SAC. Although this finding was statistically significant, it is not clinically significant (difference of 1.00 point between testing sessions). McCrea et al. demonstrated that in a high school and collegiate sample of football players, the average change in scores from baseline to post injury was 3.50 (McCrea, Kelly et al. 1998). In addition, studies in the high school population have found that there is generally no practice effect associated with the SAC (Valovich, Perrin et al. 2003).

Although not part of the primary research questions, we did observe significant main effect of session on neurocognitive index, executive function, complex attention and cognitive flexibility scores on CNSVS, with both groups scoring higher on the second testing session, than on the first testing session. This suggests that there may be a practice effect in both the control and ADHD group on the neurocognitive index, executive function, complex attention and

cognitive flexibility portions of CNSVS when the test is re-administered with 7-9 days of initial

administration. These results differ from the previous findings of Gualtieri et al; however, our

study utilized a shorter time period between testing sessions (Gualtieri and Johnson 2006).

It is important to continue examining differences in practice effects between the ADHD

population both on and off medication and control group as these comparisons have important

clinical implications. When interpreting post-injury scores, reliable change indices and practice

effects should be taken into account. However, it is important to note that these reliable change

indices and practice effects may be different in the ADHD population. In addition, they could

differ within the ADHD population, depending whether or not they are on or off medication.

Practice effects within the ADHD population needs to be examined in future studies.

Limitations

We acknowledge there are some limitations with the procedures of this study. This study

only examined individuals with ADHD who were prescribed an immediate release stimulant

medication for the treatment of ADHD.   Athlete's taking non-stimulant medications may

respond differently than our sample of ADHD athletes. Both the type and dose of medication

could influence the effects of medication. Also, the time since ADHD diagnosis, amount of time

taking current prescribed stimulant medication and ADHD subtype could influence the scores on

concussion assessment tools and the effects of the medication on scores. We attempted to control

for these variables, by making sure that all ADHD participants had been previously diagnosed

with ADHD and had taken their current stimulant medication for at least 6 months prior to their

first testing session. Heterogeneity among the ADHD group may have limited our ability to

identify significant differences across testing sessions. The ADHD group consisted of a

relatively even distribution of ADHD subtypes (hyperactive, inattentive, and combined). ADHD

individuals with different subtypes, although similar in many ways, experience different forms of the disorder. It seems possible, and likely, that ADHD individuals with different subtypes will present with different neurocognitive and postural control capabilities. Also, ADHD participants were diagnosed by different physicians prior to enrolling in our study. Discrepancies in ADHD diagnosis among diagnostic criteria could contribute to the heterogeneity of this group. Furthermore, the control group was not administered the ADHD rating scale to rule out the possibility of a missed ADHD diagnosis within the control group. Another limitation is that diagnosis of ADHD and the number of previous concussions were self reported. However, ADHD participants did meet the criteria for diagnosis on the DSM-IV criteria and did present a prescription for a stimulant medication. Additionally, the effect of stimulant medications in the ADHD group could have been mildly washed out by the practice effect between the second and third testing session. Finally, this study could have benefitted from a larger sample size. We observed several low effect sizes for some dependent variables. This may have limited our ability to detect interaction effects between groups and sessions.

Future Research

In the current study we only analyzed ADHD and control differences in postural control, neurocognition, and mental status in healthy physically active individuals. Graded symptom assessments are another integral piece to clinical concussion management. As part of our secondary analysis, we observed a significant interaction effect on the symptom scores ($F_{(2,60)}$=40.310, p<0.005). The ADHD group had a significantly higher score on the first testing session than the control group. It is interesting that the ADHD group had significantly higher scores on the first testing session, but not the second testing session, considering they were off medication both times. It is possible that the participants were not used to being off their

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medications, which caused them to experience symptoms for the first testing session. However, for the second testing session, they prepared themselves to be symptomatic and therefore, they did not report as severe symptoms. The relationship between symptoms and scores on clinical measures of concussion, especially in the athletic ADHD population requires further research.

There are several other factors that could affect the scores of ADHD individuals on concussion assessment tools. Therefore, future research should examine the influence of gender, type of medication and dose of medication on the effects of concussion assessment tools. Several studies suggest that gender, type and dose of medication could play a role in the efficacy of stimulant medications used for the treatment of ADHD. For example, a study by Swanson et al found that the optimal dose for cognitive effects was lower than that for behavioral effects, suggesting that different doses of medication could provide different benefits (Swanson 2011). A future study could examine differences between two groups of ADHD individuals, one with a higher dose of medication and the other group with a lower dose of medication. It is possible that the different groups would improve on different areas of the tests when they are on their medication. In addition, future studies could examine the effect of ADHD subtype on scores of concussion assessment tools.

Conclusions and Clinical Implications

Our findings are consistent with current findings that stimulant medications used to treat ADHD have been shown to have an effect on portions of cognitive function, including overall neurocognitive functioning, processing speed and psychomotor speed (Agay, N., Yechiam, E., Carmel, Z., & Levkovitz, 2010; Brams, M., Moon, E., Pucci, M., & Lopez, F. A., 2010; Cornforth, C., Sonuga-Barke, E., & Coghill, D., 2010). Since stimulant medications have been shown to have an effect on scores on measures of concussion, clinicians should ensure that

patients' baseline testing and post injury testing occurs under the same or similar medication statuses. ADHD athletes perform similar to controls when under the influence of stimulant medication. Sports medicine professionals should ensure that ADHD athletes complete concussion evaluation while on stimulant medication if comparing to normative data is necessary. There may be differences in practice effects between individuals with ADHD and the average population. This study found differences in practice effects on the composite memory and SAC total score. Our study suggests that it is especially important to obtain a baseline measure in individuals with ADHD, because it is difficult to compare scores to normative data. At the minimum, clinicians should note individuals with ADHD medication statuses upon baseline and post injury testing on concussion assessment tools.

APPENDIX ONE
The CNS Vital Signs^{TM} Test Battery

Verbal Memory Test (VBM) & Visual Memory Test (VIM)

Vital Signs includes parallel tests of verbal memory (word list learning) and visual memory (figure learning). The tests are virtually identical, but one uses words as target stimuli, the other, geometric shapes. The verbal memory test (VBM) is an adaptation of the Rey Auditory Verbal Learning Test. In the CNS Vital Signs version, fifteen words are presented, one by one, on the screen. A new word is presented every two seconds. The subject is asked to remember these words. Then a list of thirty words is presented. The fifteen target words are mixed randomly among fifteen new words. When the subject recognizes a word from the original list, he or she presses the space bar. After this trial of thirty stimuli, the subject goes on to do the next six tests. At the end of the battery, about 20 minutes later, the fifteen target words appear again, mixed with 15 new non-target words. The Visual Memory Test (VIM) in CNS Vital Signs is based on the Rey Visual Design Learning Test; the latter is, in turn, a parallel to the Rey Auditory Verbal Learning Test, using geometric figures rather than words, and requiring the subject to draw the figures from memory. In CNS Vital Signs, the visual memory test is just like the verbal memory test. Fifteen geometric figures are presented; the subject has to identify those figures nested among fifteen new figures. Then, after five more tests, there is a delayed recognition trial. The VBM draws from a "reservoir" of 100 plus words selected from word-frequency tables. The VIM draws from a reservoir of 60 simple geometric designs. The scoring is straightforward: correct hits and correct passes, immediate and delayed. Correct responses from VBM and VIM are summed to generate a composite memory or memory domain score. The highest score one can attain is 120; the lowest is 60. Scores below 60 suggest willful exaggeration.

Finger Tapping Test (FTT)

The FTT is one of the most commonly used tests in neuropsychology, because of its simplicity and reliability, and because it generates relevant data about fine motor control, which is based on motor speedas well as kinesthetic and visual-motor ability. The FTT is believed to be one of the most sensitive neuropsychological tests for determining brain impairment. In CNS Vital Signs, the FTT is a very simple test. Subjects are asked to press the Space Bar with their right index finger as many times as they can in 10 seconds. They do this once for practice, and then there are three test trials. The test is repeated with the left hand. The score is the average number of taps, right and left.

Symbol-Digit Coding (SDC)

Coding has been a component of the Wechsler Intelligence Scales since 1944 (Digit Symbol Substitution, DSST). The Symbol Digit Modalities Test (SDMT) is a variant of the Wechsler DSST, but the position of symbols and digits is reversed. The clinical and psychometric properties of the SDMT are similar to those of the DSST. Although the SDMT may be a "harder" test, and thus more sensitive to neurotoxicity, performance on the SDMT and the DSST are highly correlated. The SDC in CNS Vital Signs draws from a reservoir of 32 symbols. Each time the test is administered, the program randomly chooses eight new symbols to match to the eight digits. Scoring is the number of correct responses generated in 2 minutes. The total of right and left taps from the FTT and total correct responses on the SDC generates a composite score for "psychomotor speed."

The Stroop Test

In 1935, the psychologist JR Stroop demonstrated that naming is slowed when subjects are asked to name the ink color of an incongruous color word; for example, the word "blue" printed in red ink. The incongruity of word color and word meaning generates an "interference" effect. The Stroop test is still used as part of standard neuropsychological batteries and several computerized versions of the test have been developed. It is a favorite test in studies of the neurocognitive effects of CNS drugs, especially anti-epileptic drugs. There have been several versions of the Stroop test over the years. The modification adopted for CNS Vital Signs uses only four colors/color words (red, green, yellow, blue), and only one key is in play, the space bar. The test has three parts. In the first, the words RED, YELLOW, BLUE and GREEN (printed in black) appear at random on the screen, and the subject presses the space bar as soon as he or she sees the word. This generates a simple reaction time score. In the second part, the words RED, YELLOW, BLUE and GREEN appear on the screen, printed in color. The subject is asked to press the space bar when the color of the word matches what the word says. This generates a complex reaction time score. In the third part, the words RED, YELLOW, BLUE and GREEN appear on the screen, printed in color. The subject is asked to press the space bar when the color of the word does not match what the word says. This part also generates a complex reaction time score, called the "Stroop reaction time." The Stroop reaction time is, on average 120 msecs longer than the complex reaction time generated in part two of the test (range, 78-188 msecs). Part three also generates an error score. A domain score for "reaction time," or, to be more precise, information processing speed, is generated by averaging the two complex reaction time scores from the Stroop test.

The Shifting Attention Test

The Shifting Attention Test (SAT) measures the subject's ability to shift from one instruction set to another quickly and accurately. In the SAT test, subjects are instructed to match geometric objects either by shape or by color. Three figures appear on the screen, one on top and two on the bottom. The top figure is either a square or a circle. The bottom figures are a square and a circle. The figures are either red or blue; the colors are mixed randomly. The subject is asked to match one of the bottom figures to the top figure. The rules change at random. For one presentation, the rule is to match the figures by shape, for another, by color. This goes on for 90 seconds. The goal is to make as many correct matches as one can in the time allotted. The scores generated by the SAT are: number correct, errors, and response time in milliseconds. There is not a precise parallel to the SAT in the compendium of conventional neuropsychological tests, although Trails B and the Wisconsin Cart Sort are considered to be tests of shifting attention. Computerized tests, however, like the NES2, CogState and CANTAB have shifting attention tests that are not dissimilar to the SAT .A domain score for cognitive flexibility is generated by taking the number of correct responses on the SAT and subtracting the number of errors on the SAT and the Stroop test.

The Continuous Performance Test

The CPT is a measure of **vigilance** or **sustained attention** or attention over time. It has been a popular test because of its robust relationship to psychiatric disorders. It is sensitive to CNS dysfunction in general, and is not specific to any particular condition. The CPT is also sensitive, for better or worse, to the effects of various drugs. The CPT in Vital Signs is a conventional version of the test, although it is shorter than some other versions. In the Vital Signs CPT, the subject is asked to respond to target

stimulus "B" but not to any other letter. In five minutes, the test presents 200 letters. Forty of the stimuli are targets (the letter "B"), 160 are non-targets (other letters).   The stimuli are presented at random, although the target stimulus is "blocked" so it appears eight times during each minute of the test. Scoring is correct responses, commission errors (impulsive responding), and omission errors (inattention). The CPT also reports subjects' choice reaction time for each variable. A domain score for "complex attention" is generated by adding the number of errors committed in the CPT, the SAT and the Stroop.

Non-verbal Reasoning Test (NVRT)
The Reasoning test is usually less than 5 minutes as those who are capable can respond much more quickly than the time-out allows. There are 15 presentations with 14 second response time.
The test runs continuously for about 5 minutes. It consists of a series of puzzles, or visual analogies, similar to those in Raven's Progressive Matrices. The puzzles are progressively more difficult. The subject identifies the correct response from a field possible answers by selecting a number to match the answer. The report captures correct and incorrect responses as well as the reaction time.

APPENDIX TWO
The Balance Error Scoring System (BESS)
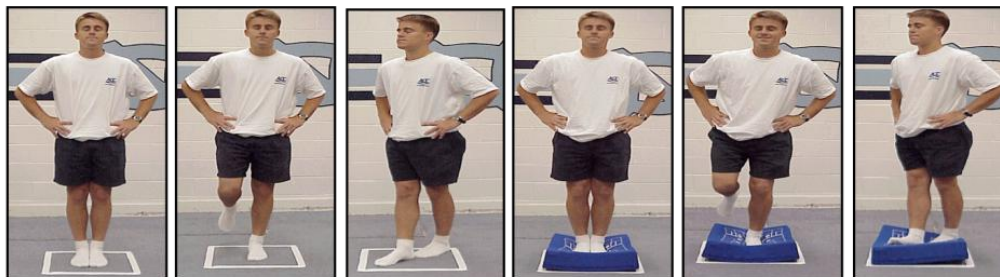
Balance Error Scoring System (BESS)		
(Guskiewicz)		

Balance Error Scoring System – Types of Errors
1. Hands lifted off iliac crest 2. Opening eyes 3. Step, stumble, or fall 4. Moving hip into > 30 degrees abduction 5. Lifting forefoot or heel 6. Remaining out of test position >5 sec
The BESS is calculated by adding one error point for each error during the 6 20-second tests.

Which **foot** was tested: ☐ Left ☐ Right
(i.e. which is the **non-dominant** foot)

SCORE CARD: (# errors)	FIRM Surface	FOAM Surface
Double Leg Stance (feet together)		
Single Leg Stance (non-dominant foot)		
Tandem Stance (non-dom foot in back)		
Total Scores:		

BESS TOTAL:

APPENDIX THREE
The Standardized Assessment of Concussion (SAC)

STANDARDIZED ASSESSMENT OF CONCUSSION - SAC	FORM A

NAME:_____

TEAM: _____ **EXAMINER:**_____

DATE OF EXAM: _____**TIME:**_____

EXAM (Circle One)**:** BLINE   INJURY   POST-GAME

          FOLLOW-UP DAY:_____

INTRODUCTION:
I am going to ask you some questions.
Please listen carefully and give your best effort.

ORIENTATION

What Month is it?_____	0	1
What's the Date today?_____	0	1
What's the Day of Week?_____	0	1
What Year is it?_____	0	1
What Time is it right now? (within 1 hr.)_____	0	1

Award 1 point for each correct answer.

ORIENTATION TOTAL SCORE ➡	

IMMEDIATE MEMORY

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order.

LIST	TRIAL 1	TRIAL 2	TRIAL 3
ELBOW	0 1	0 1	0 1
APPLE	0 1	0 1	0 1
CARPET	0 1	0 1	0 1
SADDLE	0 1	0 1	0 1
BUBBLE	0 1	0 1	0 1
TOTAL			

Trials 2 & 3: **I am going to repeat that list again. Repeat back as many words as you can remember in any order, even if you said the word before.**

Complete all 3 trials regardless of score on trial 1 & 2. 1 pt. for each correct response. Total score equals sum across all 3 trials.

Do not inform the subject that delayed recall will be tested.

IMMEDIATE MEMORY TOTAL SCORE ➡	

EXERTIONAL MANEUVERS:

If subject is not displaying or reporting symptoms, conduct the following maneuvers to create conditions under which symptoms likely to be elicited and detected. These measures need not be conducted if a subject is already displaying or reporting any symptoms. If not conducted, allow 2 minutes to keep time delay constant before testing Delayed Recall. These methods should be administered for baseline testing of normal subjects.

EXERTIONAL MANEUVERS	
5 Jumping Jacks	5 Push-Ups
5 Sit-ups	5 Knee Bends

SEE REVERSE SIDE FOR IMPORTANT USER WARNINGS

NEUROLOGIC SCREENING

LOSS OF CONSCIOUSNESS/ WITNESSED UNRESPONSIVENESS	☐ No Length:	☐ Yes
POST-TRAUMATIC AMNESIA? Poor recall of events after injury	☐ No Length:	☐ Yes
RETROGRADE AMNESIA? Poor recall of events before injury	☐ No Length:	☐ Yes

	NORMAL	ABNORMAL
STRENGTH - Right Upper Extremity	☐	☐
Left Upper Extremity	☐	☐
Right Lower Extremity	☐	☐
Left Lower Extremity	☐	☐
SENSATION - examples: FINGER-TO-NOSE/ROMBERG	☐	☐
COORDINATION - examples: TANDEM WALK/ FINGER-NOSE-FINGER	☐	☐

CONCENTRATION

Digits Backward: **I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.**
If correct, go to next string length. If incorrect, read trial 2. 1 pt. possible for each string length. Stop after incorrect on both trials.

4-9-3	6-2-9	0 1
3-8-1-4	3-2-7-9	0 1
6-2-9-7-1	1-5-2-8-6	0 1
7-1-8-4-6-2	5-3-9-1-4-8	0 1

Months in Reverse Order: **Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November...Go ahead.** 1 pt. for entire sequence correct.

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	0 1

CONCENTRATION TOTAL SCORE ➡	

DELAYED RECALL

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order. Circle each word correctly recalled. Total score equals number of words recalled.

ELBOW   APPLE   CARPET   SADDLE   BUBBLE

DELAYED RECALL TOTAL SCORE ➡	

SAC SCORING SUMMARY

Exertional Maneuvers & Neurologic Screening are important for examination, but not incorporated into SAC Total Score.

ORIENTATION	/ 5
IMMEDIATE MEMORY	/ 15
CONCENTRATION	/ 5
DELAYED RECALL	/ 5

SAC TOTAL SCORE ➡	/30

APPENDIX FOUR
ADHD RATING SCALE

Adapted from the Diagnostic and Statistical Manual of Mental Disorders-IV Diagnostic Criteria

Please answer the following questions by checking the appropriate box. The questions are pertaining to your behavior over the past six months.

When **off** your medication…	Always/ Very Often	Often	Somewhat	Rarely/ Never
do you fail to give close attention to details or makes careless mistakes in schoolwork/homework?				
do you have difficulty keeping attention on tasks or play activities?				
do you think that you do not seem to listen when spoken to directly?				
do you feel like you do not follow through on instructions and fail to finish schoolwork or chore?				
do you have difficulty organizing tasks and activities?				
do you avoid or strongly dislike tasks that require sustained mental effort (e.g., homework)?				
do you lose things necessary for tasks or activities (e.g., pencils,books, etc)?				
are you easily distracted by outside stimuli?				
are you forgetful in daily activities?				

When **off** your medication…	Always/ Very Often	Often	Somewhat	Rarely/ Never
do you fidget with hands or feet or squirm in your seat?				
do you leave your seat in situations in which remaining seated is expected (e.g., dinner table)?				
do you run about in situations where it is inappropriate?				
do you have difficulty performing tasks quietly?				
do you feel like you're "on the go" or driven by a motor?				
do you talk excessively?				
do you blurt out the answers to questions before the questions have been completed?				
do you have difficulty awaiting your turn?				
do you interrupt or intrude on others?				

do you experience the behaviors described above in two or more settings (i.e.. home and school)?____ Yes____No

ADHD Rating Scale Grading:

Inattentive sub-type:
To meet the criteria for ADHD inattentive sub-type, there must be *six or more* boxes checked in the *"*Always or very often" and the "Often" columns, for the first nine questions. In other words, the child must have at least six of these symptoms which have persisted for at least 6 months to a degree that is maladaptive (significant impairment in social, academic, or occupational functioning) and inconsistent with developmental level

Hyperactive/impulsive sub-type:
To meet the criteria for ADHD hyperactive/impulsive sub-type, six or more of the symptoms should be in the "Always
or very often" and the "Often" categories for the last nine questions.

Combined sub-type:
To meet the criteria for ADHD combined sub-type, both the inattentive and hyperactive/impulsive criteria must be met. This means that six or more "Always or very often" or "Often" boxes were checked in both the first nine questions and the last nine questions.

Participant Questionnaire

Please answer all of the questions in Part A / Part A and Part B to the best of your ability. If you have any questions, please ask your research assistant.

Part A

Gender: ☐ Male ☐ Female

What is your date of birth? _____/_____/_____
                     (month) / (date) / (year)

What year are you? Please check the correct response.

☐ Freshman   ☐ Sophomore   ☐ Junior   ☐ Senior   ☐ Fifth Year   ☐ Graduate student

How many days a week do you typically workout (cardio or resistive exercises)?
_____ days/week

How long do you typically workout for on those days? _____ minutes/day

How long have you been working out? _____ months or _____ years

Have you suffered a head injury, vestibular dysfunction or any injury that has affected your physical activity within the past 6 months? Please circle the correct response. ☐ Yes   ☐ No

If yes, please explain._____

Have you ever been diagnosed with a concussion?   ☐ Yes ☐ No

If so, how many? _____

Have you ever been diagnosed with Attention Deficit Hyperactive Disorder?   ☐ Yes ☐ No

If yes, please answer additional questions "Part B" of the questionnaire.

Part B

Have you been diagnosed with attention deficit hyperactivity disorder (ADHD)?   ☐Yes ☐No

Approximately when were you diagnosed with ADHD? _____/_____
                                                                                    (month) / (year)

Are you currently taking medication for ADHD? Please circle the correct response. ☐Yes   ☐No

Is your prescription a stimulant?   ☐Yes ☐No

When did you start taking the medication you are currently using?   _____/_____/_____
                                                                                       (month) / (date) / (year)

What days/times of the week do you typically take your medication? If any conditions cause you to take your medication (i.e. classes, tests, sporting events, etc.) please explain here as well:

Participant Questionnaire
Follow-Up

Please answer all of the questions in Part A / Part A and Part B to the best of your ability. If you have any questions, please ask your research assistant.

Part A

How many hours did you sleep last night (please round to the nearest 15 minutes)? _____hours &_____ minutes

How many classes have you had so far today?   _____

How much time have you spent in class so far today?   _____ hours &_____ minutes

How long has it been since the end of your last class?   _____ hours &_____ minutes

Are you currently taking any medications, other than for the treatment of ADHD?   ☐Yes   ☐No

If you answered yes to the previous question, please list the medications and dosage of medication you are taking:

_____
_____

Please list anything that you have had to eat today below:

Please list anything you have had to drink today and approximately how much (fluid ounces), you have had of each fluid:

Part B

How long has it been since you last took a stimulant medication (please round to the closest 15 minutes)?

_____hours &_____ minutes

If you take more than one type of stimulant medication, how long has it been since you took your other medication?

_____hours&_____ minutes   Or Circle: ___N/A_____

If you are on more than one type of stimulant medication, which one have you taken most recently?

_____   Or Circle: ___N/A_____

APPENDIX SIX
Executive Summary

Research Questions:
1. How do individuals diagnosed with ADHD perform on clinical measures of concussion when on stimulant medication compared to off stimulant medication?
2. How do individuals diagnosed with ADHD perform on clinical measures of concussion when on stimulant medication compared to matched controls?
3. How do individuals diagnosed with ADHD perform on commonly used clinical measures of concussion when off stimulant medication compared to matched controls?
4. How do individuals diagnosed with ADHD perform on clinical measures of concussion across multiple testing sessions compared to matched controls?

Independent Variables:
1. *Group:* Individuals diagnosed with ADHD, matched controls
2. *Session*: Testing session one, testing session two and testing session three
   a. *ADHD Group Conditions Within Testing Sessions*:
      i. off medication (testing session one and two)
      ii. on medication (testing session three)

Dependent Variables:
1. Scores on clinical measures of concussion
   a. CNS Vital Signs (CNSVS)
      i. 10 dependent variables: neurocognition index, composite memory domain score, verbal memory domain score, visual memory domain score, processing speed domain score, executive function domain score, psychomotor speed domain score, reaction time domain score, complex attention domain score, cognitive flexibility domain score
   b. Balance Error Scoring System (BESS)
      i. 1 dependent variables: total error score
   c. Standardized Assessment of Concussion (SAC)
      i. 1 dependent variables: SAC total score

Participants:
Participants in the study will consist of a convenience sample of 34 students from the University of North Carolina at Chapel Hill, who are physically active and between 18 and 24 years old. Eighteen of the participants will have been diagnosed with ADHD and 18 participants will be matched controls. Participants in the ADHD group will be identified through recruitment efforts, and must meet three criteria: 1) declare that they have been diagnosed with ADHD, 2) complete the ADHD rating scale to confirm they meet the ADHD criteria, 3) provide proof of a prescription for stimulant medication. The 18 control participants will be matched to ADHD participants based on gender, years of education completed, and concussion history.

Inclusion Criteria: All participants must be between eighteen and twenty-four years old and must be physically active (defined as consistently participating in at least 30 minutes of cardiovascular and/or resistive training at least 4 times per week for the past 5 months).
Exclusion Criteria: Sustained three or more concussions, known vestibular dysfunction, or any lower extremity injury that has affected physical activity or concussion, within the past 6 months.

Study Design:

Participants were recruited using a convenience sample of physically active students at UNC-CH. Both groups were administered theCNSVS, BESS and SAC on three separate occasions. The control group will complete these measures without any change in conditions. For the participants in the ADHD group, the first two testing sessions were completed "off" medication, while testing session three was completed "on" medication. For the "off" medication testing sessions, ADHD participants did not take their stimulant medication for at least 24 hours before the testing session. For the "on" medication testing session, participants in the ADHD group took their stimulant medication within one to three hours prior to the testing session. All three testing sessions for each participant occurred between seven and nine days apart and were held at approximately the same time of day (within two hours of prior testing sessions). For morning testing sessions, testing must be completed prior to the participant's first class. For evening testing sessions, testing was completed at least two hours after the conclusion of the participant's last class and the participant attended less than three hours of classes on the testing day. Efforts were made to avoid disrupting the normal medication schedule of participants with ADHD.

Prior to their first testing session, each participant filled out a questionnaire to ensure that all inclusion and exclusion criteria were met. In addition, the questionnaire includes information pertaining to the timing of stimulant medications. Testing sessions were scheduled around the convenience of the participants. Classes, sporting events and other activities requiring the use of stimulant medication will be taken into account when scheduling the testing sessions.

	T1 *(Off Medication)*	T2 *(Off Medication)*	T3 *(On Medication)*
ADHD Group n=18	⎯ X	⎯ X	⎯ X
Control Group n=18	⎯ X	⎯ X	⎯ X

Data Analysis:

The effects of medication on scores of the ADHD group, relative to the control group, and differences in scores between the control group and the ADHD group while both on and off medication, were examined using separate 2 (group) x 2 (session) mixed model repeated measures ANOVAs. Tukey post-hoc was analyses were employed when the omnibus test for interaction effects were significant. In addition, in order to examine the differences in practice effects between the control group and the ADHD group when off their medication, separate 2 (group) x 2 (session) mixed model repeated measures ANOVAs were utilized. Tukey post-hoc was analyses were employed when the omnibus test for interaction effects were significant.

Interaction of interest:
RQ1: Time session two (ADHD) vs. Time session three (ADHD)
RQ2: Time session three (ADHD) vs. Time session three (Control)
RQ3: Time session two (ADHD) vs. Time session two (Control)
RQ4: Time session one (ADHD and Control) vs. Time session two (ADHD and Control)
　　　Time session two (ADHD and Control) vs. Time session three (ADHD and Control)

The effects of attention deficit hyperactivity disorder (ADHD) and stimulant medications

on concussion assessment tools

Context: Athletes with ADHD are at an increased risk for sustaining a head injury; however, the effects of ADHD and stimulant medications on concussion assessment tools are unclear.

Objective: To examine the effects of ADHD and stimulant medications on concussion assessment tools. **Design:** Repeated measures design. **Setting:** Controlled laboratory setting.

Patients or Other Participants: Thirty-four physically active participants (17 diagnosed with ADHD, and 17 matched controls). **Interventions:** All participants were administered CNS Vital Signs (CNSVS), Balance Error Scoring System (BESS) and Standardized Assessment of Concussion (SAC) on three separate occasions, each seven to nine days apart. The ADHD group completed testing session one and two on medication and testing session three off medication.

Main Outcome Measures: Score on concussion assessment tools: CNSVS (standard scores for core domains), BESS (firm, foam and total error score), and SAC (orientation, immediate memory, concentration, delayed recall and total score). **Results:** We observed a significant interaction effect for the neurocognitive index ($F_{1,31}=6.03$, p=0.020), processing speed ($F_{1,31}=5.61$, p=0.024) and psychomotor speed ($F_{1,31}=8.957$, p=0.005), with Tukey post hoc analyses revealing that on all occasions, the ADHD group performed better on medication than off medication and the control group performing better than the ADHD group on testing session two (off medication). We observed a significant interaction effect on composite memory ($F_{1,31}=11.40$, p=0.002), with Tukey post hoc analyses revealing that the ADHD group performed better on their first testing session than they did on their second testing session. We observed a

significant group x session interaction effect for the SAC total score ($F_{1,32}$=7.79, p=0.009), with Tukey post hoc analyses revealing that the control group performed better on the first testing session than they did on the second testing session

Conclusions: Our study suggests that it is especially important to obtain a baseline measure in individuals with ADHD, because it is difficult to compare scores to normative data. Also, we found that stimulant medication have a positive impact on some scores. Therefore, baseline testing and post injury testing should occur under the same or similar medication statuses, or at minimum, individuals with ADHD's medication statuses should be noted prior to administration of concussion assessment tools. **Key Words:** traumatic brain injury, attention deficit hyperactivity disorder (ADHD), stimulant medication

Text

Concussion is a common neurological injury in sports, with an estimated 1.8 to 3.6 million cases occurring each year (Langlois, Rutland-Brown et al. 2006). This may even be an underestimate as many concussions go unreported (McCrea 2004). Concussion is a complex pathophysiological process within the brain resulting from traumatic biomechanical forces, such as a direct blow to the head, neck, face or elsewhere on the body, in which the forces are transmitted to the head (McCrory, Meeuwisse et al. 2009). The evaluation of concussion involves a multi-faceted approach including: a thorough clinical evaluation, assessment of the patient's signs and symptoms, measures of postural-stability, and cognitive or neuropsychological testing (Guskiewicz, Bruce et al. 2004; McCrory, Meeuwisse et al. 2009). Current standards recommend testing athletes on these measures prior to athletic participation, in order to serve as a baseline for comparison, in the event that the athlete sustains a concussion (Guskiewicz, Bruce et al. 2004; McCrory, Meeuwisse et al. 2009). One reason behind the use of baseline testing is to provide a unique measure of an individual's performance in the absence of injury to control for "extraneous variables", such as attentional or other disorders that may influence the testing measures (Guskiewicz, Bruce et al. 2004). An example of an attention disorder is attention deficit hyperactivity disorder (ADHD), which is a behavioral syndrome primarily characterized by hyperactivity, impulsivity and inattention (National Institute for Health and Clinical Excellence Guidelines, 2006). Attention Deficit Hyperactivity Disorder is commonly diagnosed in children, but it often persists into adulthood (Wolf 2001). In fact, it is becoming more and more common for individuals with ADHD and other related disorders to attend college, with an estimated

176,000 to 528,000 currently enrolled in universities (Wolf 2001; Shifrin, Proctor et al.

2009).

Some studies report a higher rate of injuries in individuals with ADHD, speculating

that individuals with ADHD are more likely to be inattentive and impulsive and less likely to

foresee possibly negative consequences of their behaviors (Merrill, Lyon et al. 2009). A

study by Merrill et al. showed that individuals with ADHD are more susceptible to head

injuries. Since this population may be more likely to sustain a head injury, it is essential that

individuals with ADHD are properly evaluated and treated. One way to ensure this is to

make sure athletes with ADHD are administered the recommended baseline testing on

various clinical measures of concussion. In addition, stimulant medications have been

shown to be an effective treatment for ADHD and are commonly prescribed for that purpose.

However, the use of stimulant medication on scores of clinical concussion measures is also

poorly understood (Harpin 2008). It is possible that while on stimulant medications

individuals with ADHD perform better than when off medication on clinical measures of

concussion, but no previous studies have assessed this relationship.

Clinical outcome measures provide clinicians with valuable information to utilize

during evaluation and management of concussion and offer quantitative values for use in

making return to play decisions. Individuals with ADHD are prone to head injuries;

however, the effect of ADHD on scores of commonly used concussion assessment tools is

unclear. In addition, the effects of the use of stimulant medication on these measures are also

unknown. Therefore, the purpose of this study was to examine the effects of ADHD and

stimulant medications on commonly used clinical concussion measures, including the CNS

Vital Signs (CNSVS), the Balance Error Scoring System (BESS), and the Standardized

Assessment of Concussion (SAC) in physically active individuals. A secondary purpose was to examine differences in practice effect between individuals with ADHD compared to matched controls on commonly used clinical concussion measures, including the CNSVS, the BESS and the SAC.

METHODS

We used a repeated measures design to compare an ADHD group to matched controls and to compare scores across all three testing sessions, with the ADHD group performing the first and second testing sessions off medication and the third testing session on medication. The independent variables were group (ADHD group, matched control group) and time (testing session one, testing session two and testing session three). The dependent variables were scores on CNSVS (Neurocognitive Index, composite memory standard score, verbal memory standard score, visual memory standard score, processing speed standard score, executive function standard score, psychomotor speed standard score, reaction time standard score, complex attention standard score and cognitive flexibility standard score), the BESS (firm condition error score, foam condition error score and total error score) and the SAC (orientation, immediate memory, concentration, delayed recall and SAC total score).

Participants

Participants in the study consisted of a convenience sample of thirty-four participants. Seventeen participants (nine males and eight females) were in the ADHD group (age: 21.294±2.02, previous number of concussions: 0.647±0.702) and seventeen participants (nine males and eight females) were in the matched control group (age: 21.294±2.05, previous number of concussions: 0.647±0.702). Participants in the control group were matched by gender, age and concussion history to participants in the ADHD group. Participants included

in the ADHD group had to meet the following criteria: 1) declare that they have been diagnosed with ADHD, 2) complete an ADHD rating scale, adapted from part of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) to confirm they meet the ADHD criteria, 3) provide proof of a prescription for stimulant medication. The ADHD rating scale consists of a series of questions regarding inattentiveness and hyperactivity and has been used as a diagnostic criterion for ADHD. Although, not commonly used in isolation, it identifies three separate sub-types of ADHD including inattentive, hyperactive and a combined type. In order to participate each ADHD participant had to meet the criteria of one of the three sub-types. All participants were physically active, defined as consistently participating in at least 30 minutes of cardiovascular and/or resistive training at least 4 times per week for the past five months. Individuals reporting a history of three or more previous concussions, known vestibular dysfunction, or any lower extremity injury or concussion in the past six months were excluded from both groups.

Instrumentation

CNSVS (CNS Vital Signs, LLC, Chapel Hill, NC) consists of a series of computerized neurocognitive tests. One of the purposes of CNSVS is to detect changes in neurocognitive performance over time, allowing for assistance in the evaluation of concussion. Some advantages of CNSVS include millisecond timing, allowing for accurate detection of even small cognitive changes, immediate automated scoring, ease of exporting the scores and randomized presentation of data, allowing for long-term repeated administration of the test. In addition, CNSVS allows for customized testing, meaning the test administrator can choose which tests to include in each evaluation. A multitude of cognitive domains are included and are known to be sensitive to most causes of mild

cognitive dysfunction (Gualtieri, CT and Johnson, LG 2006). Results include scores for the following clinical domains: neurocognitive index, composite memory, verbal memory, visual memory, processing speed, executive function, psychomotor speed, reaction time, complex attention and cognitive flexibility. Each participant was instructed to answer quickly while also trying to be correct, read all instructions, and to try to sustain their attention throughout the entire test. CNSVS has been shown to be both valid and reliable (Gualtieri, CT and Johnson, LG 2006). All participants were administered the test in a quiet, controlled setting. The test took approximately 30 minutes for each participant to complete.

The BESS is an objective assessment tool developed to assess postural stability following concussion. It is portable, cost-effective and can be used in the absence of a more expensive or sophisticated tool (Guskiewicz 2003; Hunt, Ferrara et al. 2009). It is also one of the most commonly used concussion assessment tools amongst athletic trainers (Ferrera et al., 2001). The BESS involves three different stances (double leg, single leg and tandem stance) which are completed twice (once on a firm surface and once on an unstable surface), for a total of six twenty second trials (Guskiewicz 2003; Hunt, Ferrara et al. 2009). An Airex medium-density foam pad (20" L x 16.4" W x 2 1/2" H) (Power Systems Airex Balance Pad 81000, Knoxville, TN) was used for the unstable surface. The test took about five minutes to administer. All trials were videotaped and scored after testing to help ensure accuracy. Errors included lifting hands off iliac crests, opening eyes, stepping, stumbling or falling, moving the hip into greater than thirty degrees of flexion or abduction, forefoot or heel losing contact with the ground or remaining out of the testing position for more than five seconds (Riemann and Guskiewicz 2000). Errors were recorded for each 20 second trial by the primary investigator. Errors were summed for firm stance trails, foam stance trials, and total

of all six trials.   The BESS has found to be both valid and reliable (Hunt et al., 2009; Barr et al., 2001; Broglio et al., 2009).

The SAC is a paper-and-pencil test that is used to evaluate cognitive ability. The SAC was designed in order to provide immediate information to athletic trainers and other medical providers regarding the management of head injuries. Along with the BESS, the SAC is also one of the most commonly used concussion assessment tools amongst athletic trainers (Ferrara et al., 2001). The SAC includes assessments of orientation, immediate recall, concentration, and delayed recall. The SAC has been shown to be both valid and reliable in college athletes (McCrea, Kelly et al. 1997; Bleiberg, Kane et al. 2000; McCrea 2001; Valovich, Perrin et al. 2003). Participants were administered a different form of the SAC containing new words lists and digit recall content at each testing session to minimize a practice effect. The SAC was administered in a quiet, controlled environment. Each test took about five minutes to administer.

Testing Procedures

Approval for the study and use of human subjects was granted by the university's institutional review board. Participants reported to the University of North Carolina at Chapel Hill Matthew Gfeller Sport-Related Traumatic Brain Injury Research Center for testing. All participants were administered the CNSVS, BESS and SAC on three separate occasions, each seven to nine days apart. The testing order was counterbalanced between all participants and participants repeated the same test order at all three sessions. Prior to data collection, all participants filled out a questionnaire to ensure that all inclusion and exclusion criteria were met.

The control group was administered the CNSVS, BESS and SAC on three separate

occasions, without any change in conditions. For the participants in the ADHD group, the

first two testing sessions were completed off medications (meaning they had not taken their

medication for at least twenty-four hours prior to the testing session), while the third testing

session was completed on medication (meaning they had taken their medication between one

and three hours prior to the testing session). All three testing sessions for each participant

occurred seven to nine days apart and were held at approximately the same time of day

(within two hours of prior testing sessions). For morning testing sessions, testing was

completed prior to the participant's first class. For evening testing sessions, testing was

completed at least two hours after the conclusion of the participant's last class and the

participant had three hours or less of classes on the testing day. Every effort was made to

avoid disrupting the normal medication schedule of participants with ADHD. A

questionnaire was also administered to all participants prior to each testing session, which

included information regarding hours of sleep, hydration and eating habits.

Data Analysis

All data were analyzed using SPSS Version 17.0 (SPSS Inc, Chicago, Illinois). An

apriori alpha level was set at 0.05. The effects of medication on scores of the ADHD group,

relative to the control group, and differences in scores between the control group and the

ADHD group while both on and off medication, were examined using separate 2 (group) x 2

(session) mixed model repeated measures ANOVAs. Tukey post-hoc was analyses were

employed when the omnibus test for interaction effects were significant. In addition, in order

to examine the differences in practice effects between the control group and the ADHD

group when off their medication, separate 2 (group) x 2 (session) mixed model repeated

measures ANOVAs were utilized. Tukey post-hoc was analyses were employed when the omnibus test for interaction effects were significant.

RESULTS

The effects of stimulant medication

We examined the effects of stimulant medication in the ADHD group relative to matched controls on scores of concussion assessment tools comparing session one (ADHD-off medication) to session three scores (ADHD-on medication).

CNSVS

We did not observe any significant group x session interactions or main effects for scores on ***composite memory***, ***verbal memory***, ***visual memory***, ***executive function***, ***complex attention*** or ***cognitive flexibility***. The absence of an interaction effect, combined with an absence of any main effects may mean that there was no added effect of stimulant medication for these CNSVS subtests.   However, we observed a significant interaction effect for the ***neurocognitive index*** ($F_{1,31}$=6.03, p=0.020). Tukey post hoc analyses revealed that the ADHD group performed better on medication than off medication (d_{crit}=4.91). We also noted a significant interaction effect for ***processing speed*** ($F_{1,31}$=5.61, p=0.024) (Figure 4.5). Tukey post hoc analyses revealed that the ADHD group performed better on medication than off medication (d_{crit}=5.18). Finally, we observed a significant interaction effect for ***psychomotor speed*** ($F_{1,31}$=8.957, p=0.005) (Figure 4.7). Once again, Tukey post hoc analyses revealed that the ADHD group performed better on medication than off medication (d_{crit}=4.06).

Balance Error Scoring System

We did not observe any significant interaction effects for **BESS** total score. However, we did observe a significant session main effect ($F_{1,32}=5.17$, p=0.030) (Figure 4.11). The ADHD and control group both performed better on the third testing session than they did on the second testing session. Although the ADHD group performed better on their medication than off their medication, the control group improved between the second and third testing session as well. This indicates that the increase in scores is likely due to a practice effect, as opposed to the medication.

Standardized Assessment of Concussion

We did not observe any significant interaction effects for **SAC** total score. However, we did observe a significant session main effect ($F_{1,32}=16.000$, p<0.005). The ADHD and control group both performed better on the third testing session than they did on the second testing session. Although the ADHD group performed better on their medication than off their medication, the control group improved between the second and third testing session as well. This indicates that the increase in scores is likely due to a practice effect, as opposed to the medication.

Attention Deficit Hyperactivity Disorder (ADHD) compared to controls

We examined the differences in scores on concussion assessment tools between the ADHD group when they were on their medication (session three) compared to matched controls.   We also examined the differences in scores on concussion assessment tools between the ADHD group when they were off their medication (session two) compared to matched controls (session two). The same 2x2 repeated measures ANOVA models conducted

to examine the effects of stimulant medication on concussion assessment tools was also used for this analysis.

CNS Vital Signs

As per above, we did not observe any significant group x session interactions or main effects for scores on ***composite memory***, ***verbal memory***, ***visual memory***, ***executive function***, ***complex attention*** or ***cognitive flexibility***. The absence of an interaction effect, combined with an absence of any main effects reflects that there was not a statistically significant difference between the two groups at session three on any of these subtests. we observed a significant interaction effect for the ***neurocognitive index*** ($F_{1,31}$=6.03, p=0.020) (Figure 4.1). Tukey post hoc analyses revealed that the control group performed better than the ADHD group on the second testing session (d_{crit}=4.91).We also noted a significant interaction effect for ***processing speed*** ($F_{1,31}$=5.61, p=0.024) (Figure 4.5). Again, Tukey post hoc analyses revealed that the control group performed better than the ADHD group on the second testing session (d_{crit}=5.18). Finally, we observed a significant interaction effect for ***psychomotor speed*** ($F_{1,31}$=8.957, p=0.005) (Figure 4.7). Once again, Tukey post hoc analyses revealed that the control group performed better than the ADHD group on the second testing session (d_{crit}=4.06). However, post hoc analyses revealed no significant differences in scores between the ADHD and control group on the third testing session.

Balance Error Scoring System

We did not observe any significant interaction or group main effects for the **BESS** Total Score. The absence of an interaction effect combined with the absence of any group

main effects means that there not a statistically significant difference between the two groups at session three for the BESS.

Standardized Assessment of Concussion

We did not observe any significant interaction or group main effects for the **SAC** total score. The absence of an interaction effect combined with the absence of any group main effects means that there is no statistically significant difference between the two groups at session three for the SAC.

Practice Effects

Separate 2x2 repeated measures ANOVAs were also utilized to evaluate the differences in practice effect between individuals with ADHD compared to matched controls on commonly used clinical concussion measures, including the CNSVS, the BESS and the SAC between an initial taking of the tests (session one- ADHD: off medication) and a second taking of the tests (session two- ADHD: off medication).

CNS Vital Signs

We did not observe any significant group x session interactions or main effects for scores on *verbal memory*, *visual memory*, *processing speed, psychomotor speed,* or *reaction time.* We did observe a significant interaction effects on *composite memory* ($F_{1,31}=11.40$, p=0.002) (Figure 4.14). Tukey post hoc analysis revealed that the ADHD group performed better on their first testing session than they did on their second testing session ($d_{crit}=6.37$). In addition, we observed a significant session main effect for scores on the *neurocognitive index* ($F_{1,31}=7.85$, p=0.009), *executive function* ($F_{1,31}=17.30$, p<0.005), *complex attention* ($F_{1,31}=5.46$, p=0.026) and *cognitive flexibility* ($F_{1,31}=17.24$, p<0.005) (Figures 4.13,

4.18 and 4.22). In all cases, the scores of both the ADHD and control groups were higher on the second testing session, than on the first testing session, suggesting a significant practice effect existed for these subtests independent of group.

Balance Error Scoring System

We did not observe any significant group x session interactions or main effects for the **BESS** total score, suggesting there is no practice effect for either group

Standardized Assessment of Concussion

We observed a significant group x session interaction effect for the **SAC** total score ($F_{1,32}$=7.79, p=0.009)(Figure 4.24). Tukey post hoc analyses revealed that the control group performed better on the first testing session than they did on the second testing session (d_{crit}=0.81), suggesting there is not a practice effect. In addition, post hoc analyses revealed that the ADHD group performed statistically worse than the control group at both the first and second testing sessions, but closed the gap to some degree at the second session. Thus, to no surprise the results revealed a main effect for group ($F_{1,32}$=11.33, p=0.002), with the control group performing better than the ADHD group while off their medication.

DISCUSSION

The effect of ADHD on cognitive function has been widely researched; however the effect of ADHD on concussion measures is not as well understood. The most important result from our study is that individuals with ADHD perform better on select neurocognitive measures when on their prescribed stimulant medication. The ADHD subjects in our study presented with better processing speed, psychomotor speed and overall neurocognitive performance compared to when off medication (Research Question 1). The improved scores

by the ADHD group in the absence of any improvement in the control group rules out the possibility that the improvement was due to a practice effect between session two and three. The stimulant medication had a positive effect on these cognitive domains and should be an important consideration for clinicians when administering cognitive tests.

Despite these improvements, there were no differences between the ADHD and control group on neurocognitive, balance or mental status performance as measured by the SAC when the ADHD group was on their medication (Research Question 2). However, the control group performed better than the un-medicated ADHD group on processing speed, psychomotor speed, and overall neurocognitive performance (Research Question 3). The ADHD group performed better on their first testing session than their second testing session on composite memory, while there was no change in scores in the control group. Conversely, the control group performed better on the first testing session on the *SAC*, while there was no difference in the ADHD group (Research Question 4).

Effects of Stimulant Medications

We observed a positive effect of medication on the neurocognitive index (NCI), processing speed and psychomotor speed portions of CNS Vital Signs, while we did not observe any effect of medication on composite memory, verbal memory, visual memory, executive function, reaction time, complex attention or cognitive flexibility. In addition, the ADHD group improved on the BESS total score and SAC total score, when they were on their medication, compared to off medication. However, the improved BESS and SAC total scores cannot be attributed to the effects of medication, because the control group improved

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as well. In addition, the change would likely not be considered clinically significant (changes of 1.42 and 1.00 respectively).

We expected to see the medications have a positive effect on overall neurocognitive functioning by increasing arousal of the Central Nervous System (CNS). The theory behind stimulant medications is that they increase arousal and alertness of the (CNS) through stimulation of norepinephrine and dopamine (Vaughan, et al., Volkow et al 1998, Bymaster et al. 2002 and Rowe et al.). One study found that stimulants suppress the locus coeruleus, which reduces stimulation of the thalamic reticular nucleus, ultimately improving cortical arousal (Rowe et al). Therefore, it is not surprising that the ADHD group improved on overall neurocognitive functioning while medicated. In fact, a study by Riordan et al, also found that a stimulant medication improved overall performance on a battery of neuropsychological tests including measures of motor speed, processing speed and distractibility in an adult ADHD group (Riordan et al. 1999). Furthermore, we expected to observe positive effects of medication on both the processing speed and psychomotor speed scores, because they are measures of attention and focused concentration (or distractibility) and stimulant medications have been shown to improve concentration and attention (Hickey 1999).

We expected to observe a positive effect of medication on all measures of CNSVS, but did not observe an effect of medication on measures of composite memory, verbal memory, visual memory, reaction time, complex attention or cognitive flexibility. In addition, we expected to see a positive effect of medication on the BESS and SAC. A probable reason the medication did affect many factors of the CNSVS, BESS or SAC is because the ADHD group did not have deficits in these categories compared to a control group, when they were

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off their medication. Although previous studies have found stimulant medications to have an effect on some of domains of CNS Vital Signs, it has also been observed that as individuals with ADHD age and mature, their test scores normalize (Gualtieri et al, etc.). Therefore, a collegiate population who is likely to be intelligent and motivated and have their ADHD treatment under control is more likely to have normal neurocognitive, balance and mental status scores compared to an adolescent or child population.

Our study suggests that although stimulant medication did not appear to improve balance or mental status, it did affect some neuropsychological components, including overall neurocognitive performance, processing speed and psychomotor speed. Based on the results of our study, ADHD athletes should complete both their baseline and post-injury tests on their prescribed stimulant medications. The majority of stimulant medications are prescribed to be taken on a daily basis. This study observed that when the ADHD participants were on their medication, there were no differences between their scores and the control group's scores. However, when the ADHD group was off their medication, there were difference in neurocognitive performance, processing speed and psychomotor speed.

In some cases, it may not be feasible for the individual to be on their medication for both the baseline and post injury testing. For example, in some settings, it may be too difficult to notify all ADHD athletes who are prescribed a stimulant medication to make sure they take their medication prior to the testing session. When this is the case, at the very minimum, the medication status of the athlete should be documented and held constant across sessions. Questions such as: "Have you ever been diagnosed with attentional deficit hyperactivity disorder (ADHD), attentional deficit disorder (ADD) or any other learning disability?", "If so, when were you diagnosed?", "Do you currently take any type of

medication for the treatment of ADHD, ADD or other learning disability?", "When did you first start taking the medication you are currently taking?", "What type of medication are you on and what is your dose?", "How often do you take your medication?", "Do you think your medication works?" and "How long has it been since you last took your prescribed medication?", should be added to the standard battery of concussion assessment tools. This will allow for a better interpretation of post-injury scores.

Attention Deficit Hyperactivity Disorder (ADHD)

We observed differences in scores on the NCI, processing speed and psychomotor speed portions of CNS Vital Signs between the control group and the ADHD group, when the ADHD group was off their medication. On all three domains, the control group performed better than the ADHD group. There was no significant difference between the groups on measures of balance or mental status. While we initially hypothesized that the control group would perform better than the ADHD group on all measures of neurocognitive functioning, balance and mental status, it is fairly well supported that the ADHD group may not be impaired with certain types of memory, or balance. Most studies that showed memory impairment within the ADHD population studied working memory (which involves retaining and manipulating information for several seconds), or recall memory, while CNS Vital Signs assesses recognition memory (Gropper and Tannock 2009; Valera, Brown et al. 2009). It is likely that recognition memory is easier for the ADHD population and therefore they are able to perform similarly to a control group on the verbal and visual memory measures.

However, it is interesting that there were no significant differences between the groups on measures of reaction time, complex attention and cognitive flexibility, because they have been found to be influenced by ADHD (Gualtieri, etc.). It is possible that changes

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were not seen in this group, because individuals with ADHD who are able to perform academically at the collegiate level may have a milder form of the disorder (Wilmhurst L, et al 2009). In addition, compared to the adolescent population, where the cognitive and balance deficits are typically seen, the collegiate population likely tends to be more mature and is more likely to have found the best treatment for their disorder. It has been observed that individuals with ADHD experience a decrease in symptoms as they age (Hart et al. 1995). Since differences between the adolescent and adult ADHD population has been shown, it has even been suggested that age-specific assessments of ADHD should be considered (Ramtekkar et al. 2009). Futhermore, a study by Schwartz et al. found that there was no difference between scores on Stroop interference tasks between an ADHD and age matched controls, and in our study the scores from the Stroop interference tasks make up part of the scores for reaction time, complex attention and cognitive flexibility scores (Schwartz K et al).

Our study indicates that when ADHD individuals are on their stimulant medication, their scores are comparable to those of matched controls. This provides an important implication for serial testing of ADHD athletes. If individuals with ADHD are comparable to matched controls, when they are on their stimulant medications, then it is desirable that individuals with ADHD to take their stimulant medication prior to baseline and post-injury testing. In the case where an athlete with ADHD sustains a concussion, but does not have a baseline measure, the team physician and athletic trainer should instruct the athlete to take their stimulant medication prior to follow-up testing to allow for comparisons with normative data.

Recent recommendations suggest that baseline testing on neurocognitive, postural control, and symptomotology measures be completed prior to sport exposure for all athletes, so that appropriate comparisons can be made post-injury. Our study suggests that both ADHD and stimulant medications affect scores on concussion assessment tools. Clinicians should make an effort to identify athletes with ADHD prior to concussion baseline evaluation and treat these athletes with special care to ensure quality baseline scores.

Practice Effects

A secondary aim of our study was to examine differences in practice effects between the control group and the ADHD group when they were off their medication. We observed that the ADHD group performed better on the composite memory portion of CNSVS on their first testing session than their second testing session, while there was no significant difference between testing sessions in the control group. Additionally, the control group performed better on the first testing session than on the second testing session for the SAC total score, while there was no significant difference between testing sessions in the ADHD group. CNSVS has been shown to be both valid and reliable (Gualtieri et al. 2006). However, there may be differences in test-retest reliability between the ADHD and control population. We hypothesized that the control group may benefit from a practice effect between the first and second testing session, while the ADHD group might not. Our study suggests that the ADHD group declined in performance between the first and second testing session on the composite memory portion of CNSVS. This could be due to the fact that the ADHD group performed better on the first testing session, due to the novelty effect, or the excitement associated with completing a task for the first time, while the task was not new during the second testing session and they knew that they would have to sustain their

attention for a long period of time (Poppenk 2010). Composite memory was likely affected because the score is a combination of scores on both verbal and visual memory, in which tasks are repeated the end of the testing battery. Therefore, they require attention over an extended period of time.

Another interesting finding is that the control group had decreased scores between their first and second testing session on the SAC. Although this finding was statistically significant, it is not clinically significant (difference of 1.00 point between testing sessions). McCrea et al. demonstrated that in a high school and collegiate sample of football players, the average change in scores from baseline to post injury was 3.50 (McCrea 1998). In addition, studies in the high school population have found that there is generally no practice effect associated with the SAC (Valovich McLeod et al. 2004, McLeod et al. 2003).

Although not part of the primary research questions, we did observe significant main effect of session on neurocognition index, executive function, complex attention and cognitive flexibility scores on CNSVS, with both groups scoring higher on the second testing session, than on the first testing session. This suggests that there may be a practice effect in both the control and ADHD group on the neurocognition index, executive function, complex attention and cognitive flexibility portions of CNSVS when the test is re-administered with 7-9 days of initial administration. These results differ from the previous findings of Gualtieri et al; however, our study utilized a shorter time period between testing sessions (Gualtieri et al. 2006).

It is important to continue examining differences in practice effects between the ADHD population both on and off medication and control group as these comparisons have important clinical implications. When interpreting post-injury scores, reliable change indices

and practice effects should be taken into account. However, it is important to note that these reliable change indices and practice effects may be different in the ADHD population. In addition, they could differ within the ADHD population, depending whether or not they are on or off medication. Practice effects within the ADHD population needs to be examined in future studies.

Limitations

We acknowledge there are some limitations with the procedures of this study. This study only examined individuals with ADHD who were prescribed an immediate release stimulant medication for the treatment of ADHD.   Athlete's taking non-stimulant medications may respond differently than our sample of ADHD athletes. Both the type and dose of medication could influence the effects of medication. Also, the time since ADHD diagnosis, amount of time taking current prescribed stimulant medication and ADHD subtype could influence the scores on concussion assessment tools and the effects of the medication on scores. We attempted to control for these variables, by making sure that all ADHD participants had been previously diagnosed with ADHD and had taken their current stimulant medication for at least 6 months prior to their first testing session. Heterogeneity among the ADHD group may have limited our ability to identify significant differences across testing sessions. The ADHD group consisted of a relatively even distribution of ADHD subtypes (hyperactive, inattentive, and combined). ADHD individuals with different subtypes, although similar in many ways, experience different forms of the disorder. It seems possible, and likely, that ADHD individuals with different subtypes will present with different neurocognitive and postural control capabilities. Also, ADHD participants were diagnosed by different physicians prior to enrolling in our study. Discrepancies in ADHD diagnosis among

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diagnostic criteria could contribute to the heterogeneity of this group. Furthermore, the control group was not administered the ADHD rating scale to rule out the possibility of a missed ADHD diagnosis within the control group. Another limitation is that information such as the diagnosis of ADHD and number of previous concussionswere self reported.However, ADHD participants did meet the criteria for diagnosis on the DSM-IV criteria and did present a prescription for a stimulant medication. Additionally, the effect of stimulant medications in the ADHD group could have been mildly washed out by the practice effect between the second and third testing session.   Finally, this study could have benefitted from a larger sample size. We observed several low effect sizes for some dependent variables. This may have limited our ability to detect interaction effects between groups and sessions.

Future Research

In the current study we only analyzed ADHD and control differences in postural control, neurocognition, and mental status in healthy physically active individuals. Graded symptom assessments are another integral piece to clinical concussion management. As part of our secondary analysis,we observed a significant interaction effect on the symptom scores ($F_{(2,60)}$=40.310, p<0.005). The ADHD group had a significantly higher score on the first testing session than the control group. It is interesting that the ADHD group had significantly higher scores on the first testing session, but not the second testing session, considering they were off medication both times. It is possible that the participants were not used to being off their medications, which caused them to experience symptoms for the first testing session. However, for the second testing session, they prepared themselves to be

symptomatic and therefore, they did not report as severe symptoms. The relationship

between symptoms and scores on clinical measures of concussion, especially in the athletic

ADHD population requires further research.

There are several other factors that could affect the scores of ADHD individuals on

concussion assessment tools. Therefore, future research should examine the influence of

gender, type of medication and dose of medication on the effects of concussion assessment

tools. Several studies suggest that gender, type and dose of medication could play a role in

the efficacy of stimulant medications used for the treatment of ADHD. For example, a study

by Swanson et al found that the optimal dose for cognitive effects was lower than that for

behavioral effects, suggesting that different doses of medication could provide different

benefits (Swanson 2011).   A future study could examine differences between two groups of

ADHD individuals, one with a higher dose of medication and the other group with a lower

dose of medication. It is possible that the different groups would improve on different areas

of the tests when they are on their medication. In addition, future studies could examine the

effect of ADHD subtype on scores of concussion assessment tools.

Conclusions and Clinical Implications

Our findings are consistent with current findings that stimulant medications used to

treat ADHD have been shown to have an effect on cognitive function (Agay 2010, Brams

2010, Cornforth 2010). Since stimulant medications have been shown to have an effect on

scores on measures of concussion, clinicians should ensure that patients' baseline testing and

post injury testing occurs under the same or similar medication statuses. ADHD athletes

perform similar to controls when under the influence of stimulant medication. Sports

medicine professionals should ensure that ADHD athletes complete concussion evaluation while on stimulant medication if comparing to normative data is necessary. There may be differences in practice effects between individuals with ADHD and the average population. This study found differences in practice effects on the composite memory and SAC total score. Our study suggests that it is especially important to obtain a baseline measure in individuals with ADHD, because it is difficult to compare scores to normative data. At the minimum, clinicians should note individuals with ADHD medication statuses upon baseline and post injury testing on concussion assessment.

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